IRRIGATION WATER FROM SMALL SCALE EXCAVATIONS IN A DRY RIVER BED

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ABSTRACT

Northern Nigeria has a wide range of rainfall conditions, varying from an average annual rainfall of 60 inches in the southern-most parts to 15 inches in the extreme north. In all cases precipitation occurs during only limited portions of the year and during the dry season, crop cultivation is virtually at a stand-still. Owing to the ever-present problem of a short-age of water in most of the rivers in Northern Nigeria and the increasing demand for food and fibre, it is essential to tap the groundwater supplies as this is the largest available source of fresh water on earth.

The object of this study is to determine

(i) the existence and extent of groundwater inaa river basin,

(ii) the theoretical and practical yield of shallow wells situated in a dry river bed,

(iii) the effective method of retaining banks in such wells

(iv) the suitability of the water and land for irrigation practices,

(v) reliable and inexpensive methods of raising the water for irrigation purposes, and

(vi) whether such a project is economically desirable.

The area chosen for the study is the Kubanni River Basin which lies almost in the centre of the Loess Plain soils- Map I. The Loess Plain soils are reputed to be very excellent agricultural land as they are formed by infilling of fine eaolian drift on a sedentary iron pan peneplain. The whole of Zaria Province, southern parts of Katsina, Kano and smaller areas adjoining Sokoto and Niger are areas in this soil unit.

The results of this study may be reliably used in those areas mentioned above and all other similar areas in Nigeria without the necessity of having to make expensive trials.

The methods of measurement and analysis are discussed in the text. It is shown that for irrigation purposes the quality of water from the shallow excavation in the river bed, rather than the quality, proves the limiting factor.

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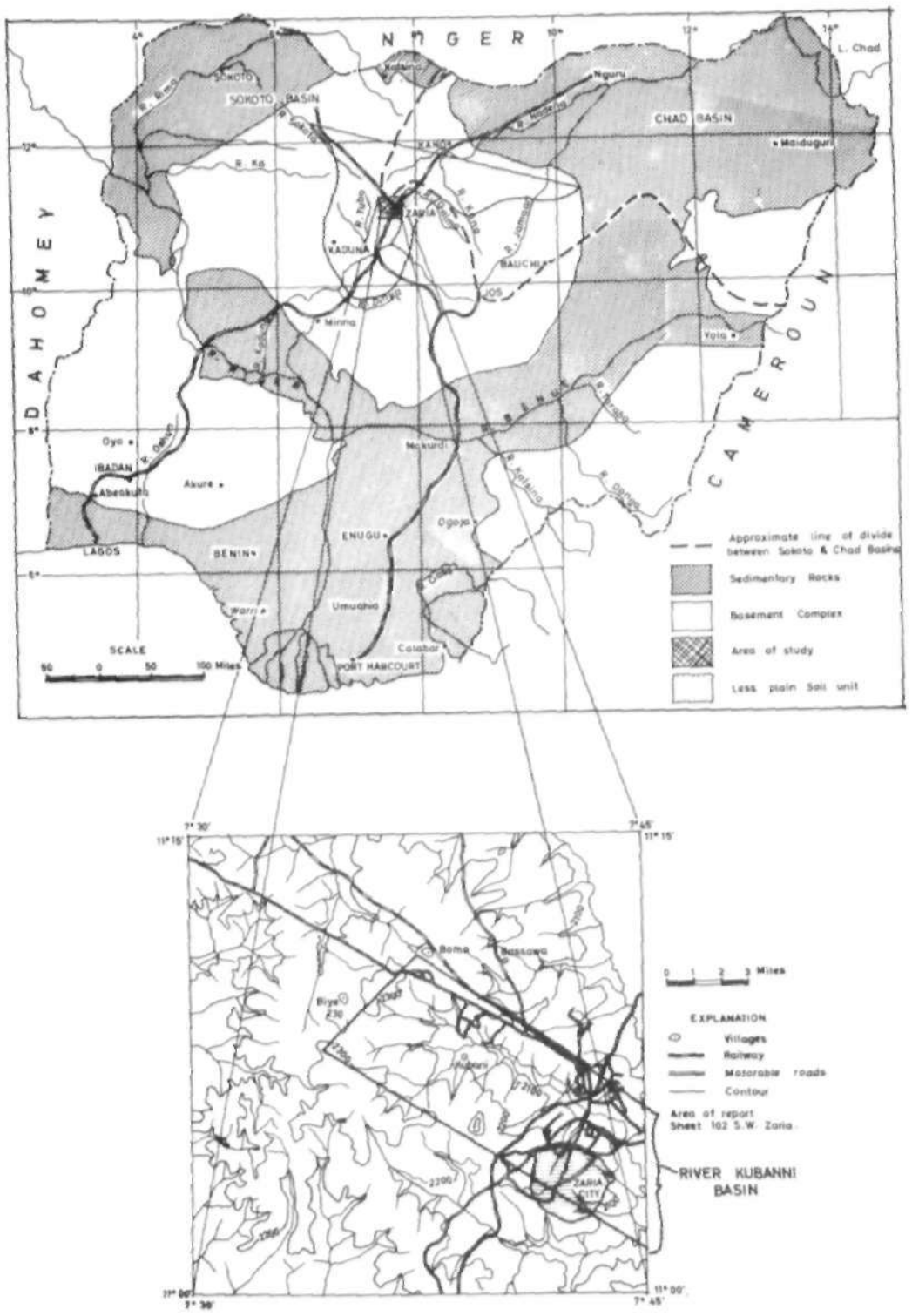
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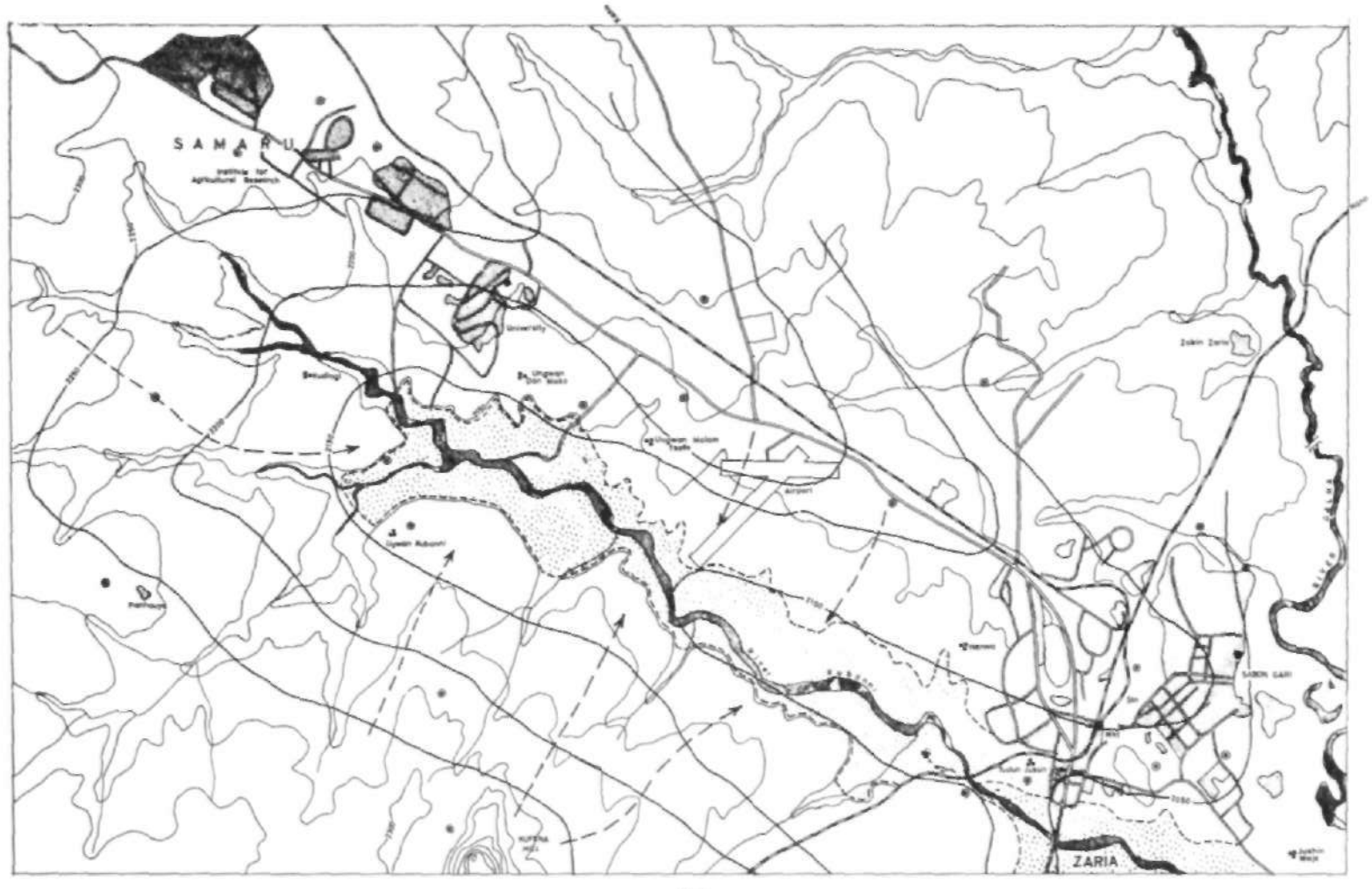
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MAP 1 LOCATION MAP



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TOPOGRAPHICAL AND WATER TABLE CONTOUR MAP



SCALE

LEGEND

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ZARIA

PART I

ENVIROMENTAL STUDIES

1.1 Introduction:

Catchment areas generally form the units which are selected for hydrological study. Hydrological studies are of great value in solving practically all problems of water supply, whether it be the prediction of flood peaks, the determination of low flows of rivers and the capacities of groundwater aquifers which could be utilised for irrigation. Irrespective of the ultimate objective of the hydrological study, the basic approach is to evaluate quantitively the elements of the hydrological characteristics of the basin, viz geographical position, physiographical features geology, climate, vegetation and agriculture. Such a detailed knowledge of the enviromental factors is essential if the optimum development and utilization of any agricultural area is to be achieved.

1.2 Geographical position

The River Kubanni Basin which forms the subject of this analysis is situated within the southwest quadrant of the half degree Zaria Sheet 102 - obtainable from Northern Nigeria Survey Department, Kaduna. It is bounded by Longitude 7^{o} 35'E and 7^{o} 45'E and Latitude 11^{o} 5'N and 11^{o} 12'N. This is in the semi-arid region of Nigeria.

The elevation ranges from 2,000 to 2,400 feet above sea level - Map I

1.3 Physiographical features

MAP II shows the topographical contour of the area, the rivers and streams, wells, and the groundwaters contour. The total catchment basin covers an area of approximately 45 square miles. Three main topographical characteristics are prominent in the basin, namely:

(i) The River Valley: The valley is a shallow depression to the north-west of the city of Zaria and the River Kubanni is characterised by a sluggish, meandering water course and originates in the Samaru highlands. It is essentially a flood conveyance channel to the main River Galma. Shortly after a sizeable amount of rainfall, the flood rises to a level of about 3 feet; otherwise the flow depth during the rainy season is usually below 1 foot. The river bed is between 2,000 and 2,050 feet above mean sea level. The river bed surface dries off completely during the months between October to April.

(ii) The Fertile Plateau: The plateau forms part of undefined banks of the River Kubanni and is occassionally interupted by gorges and low resistance escarpments. It appears in patches along the river bank, within an elevation of between 2,050 and 2,100 feet.

(iii) The Highlands: These are in the range between 2,100 and 2,400 feet above mean sea level and are mostly eroded. The uplands are dotted by asymmetrically shaped hills and inselbergs, such as the Kufena Hill.

The three topographical characteristics described above - the Valley, the Plateau, and the Highlands - are common to the catchment basins of most rivers overlying the crystalline basement complex rocks of Nigeria (see Map 1). Most of these rivers are either dried up during the dry season or contain strings of small pools along their beds.

1.4 Geological review

The area is underlain by the crystalline rocks of the Pre-Cambrian Basement Complex composed of high grade pelific schists. Overlying the crystalline rocks are the decomposed granite and gneiss schists. The overburden is fine to medium, grained and fairly indurated sands. The sands are brown to brownish red and are capped at higher elevations by patches of lateritised terraces. Preez (1952) described these sands as products of Tertiary Peneplanation.

1.5 Climate

The climate of the area falls into the Aw type of Koppens climatic classification - Trewartha (1956). The climatic condition of the area may be summarised as follows

(i) Precipitation

Most of the rains supplied by conventional storms which are of the advance pattern and which have an initial peak of high intensity, wailing off into drizzles. As is characteristic of a semi-arid enviroment, the rainfall, though not scanty in amount, is variable in its distribution, as is evident from table I which gives the standard deviation and the coefficient of variation.

TABLE I

Rainfall Distribution

Month	Standard deviation (inches	Coefficient of variation %
April	.39	13.2
May	.38	6.6
June	.29	6.2
July	.79	9.4
August	1.10	9.9
September	0.42	7.3
October	.29	-

The month is an unsatisfactory period for use in agricultural experiments requiring statistical analysis because it varies in length from 28 to 31 days, so that total rainfall is not directly comparable and average rainfall has to be weighted.

The week is considered suitable period because weekly totals can readily be added to give seasonal, annual and other periodic totals as required. In order to assess long term crop risks weekly rainfall analysis is made using the Manning's method of 1:1 confidence limits of expected rainfall. The results are as shown in Fig.1. From the curves it is evident that there is likely to be sufficient rainfall for crop raising from the second week in May to the end of September.

The annual average rainfall is 44 inches some 60% of which falls in the months of May-July. There is little or no rainfall from October to April.

(ii) Temperature

The average annual temperature is about 70°F. The month of January can be relative cold, with morning temperature as low as 46°F; otherwise there is little

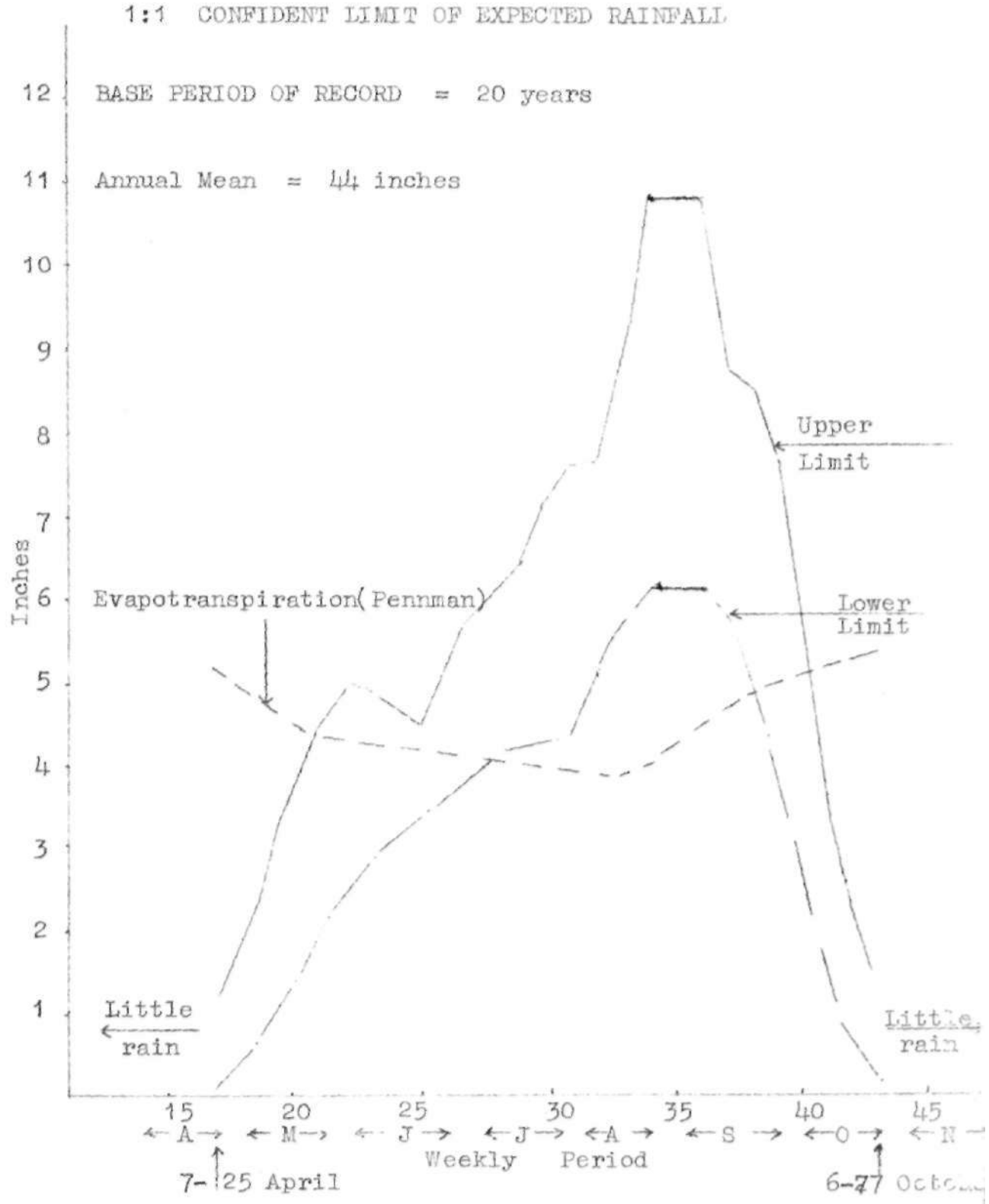

1:1 CONFIDENT LIMIT OF EXPECTED RAINFALL
BASE PERIOD OF RECORD = 20 years
Annual Mean = 44 inches
Inches
12
11
10
9
8
7
6
5
4
3
2
1
Upper Limit
Lower Limit
Evapotranspiration(Penmman)
Little rain
Little rain
15
20
25
30
35
40
45
← A → ← M → ← J → ← J → ← A → ← S → ← O → ← N
Weekly Period
7-25 April
6-7 Oct

Fig I

variation between the maximum and minimum temperature throughout the year:

(iii) Seasons

There are two distinctive seasons: dry and wet seasons, and the beginning of the wet season is defined as the date when the cumulative rainfall just maintains evapotranspiration (Penman estimates), and the end as when evapotranspiration is not maintained. From the the analysis of more than 40 years of rainfall records and evapotranspiration rates for the Samaru Dam Catchment Basin adjacent to Kubanni River Basin, on 82% of occasions, the wet season began in the second week of May and ended at the end of September. Omolokun (1968). The dry season includes the harmattan period during which dews are common in the early mornings.

1.6 Vegetation

The vegetation consists of grassland, growing in tussocks, and of thick-barked woodland and falls within the Northern Guinea zone of the Savannah - Keay (1960). Most of the river banks in this zone have vegetation of the rain forest type, but along the bank of Kubani

River, this has been modified by extensive farming, bush burning and animal grazing. During the dry season the vegetation is sparse and stunted.

Agricultural activities are restricted mainly to the fertile parts of the Plateau and the Highlands. The major crops which are rainfed are sorghum, groundnuts, cotton vegetables and sugar cane.

During the dry season when the water-table is sufficiently high, capillary rising water and dews cover the early requirements of the crops which are mostly vegetables. Very often, the 'shadoof' method of irrigation is resorted to in bringing the crops to maturity. In the 'shadoof' system, water is lifted from the wells in a leather bucket with a capacity of ½-1 gallon. The lifting is facilitated by a lever device with a clay counter weight. The water is emptied into small ditches built in levees and is then applied to unit areas of some 3 feet square. The cultivated crops are usually irrigated between 6.00 a.m. and 6.00 p.m.

Weak soil structures coupled with comparatively steep slopes of the catchment basin, unstable equili-

brium of the components of the natural vegetation, and the alternation between periods of fairly high rainfall intensity and extreme desiccation, combine to render the catchment more than usually prone to erosion.

The climatological data of the area are as shown in Appendix I.

PART II

GROUND WATER PATTERNS

2.1 Introduction

The investigation of the occurrence and movement of the groundwater which is to be exploited demands the demands the study of a number of factors including the amount of rainfall and its variability from season to season, water-table fluctuations, groundwater contours and its direction of flow. Naturally, the degree to which it will be possible to estimate resources varies with the geological conditions under which the water occurs. Barber et al (1962) on the geological investigations around this basin pointed out that the groundwater is contained in the superficial deposits or decomposed rocks of granite or gneiss schists. The groundwater in the superficial deposits at the lower elevations may be up to 20 feet deep, whilst at the higher ground levels the water table can be as much as 80 feet below the ground surface.

2.2 Setting for groundwater study

A grid of observation wells as shown in Map II were

used in this study. Use was also made of the results of groundwater probes by the Resistivity Method carried out on part of the lower slopes of the basin near the University by Ososami (1968).

The groundwater levels in the wells were measured early in the mornings using water level Indicator Model DR 760A which is a self contained transistorized battery operated instrument.

A grid of rainfall gauges were installed on the catchment to correlate the changes in water-table height with rainfall.

2.3 Results

(i) Rainy season pattern

The rise in the water-table occurs around the third week of July when the cumulative rainfall is 20 $\pm$ 2 inches. This 20 inches is a rough measure of the quantity of water evaporated or transpired in the course of the dry season. The peak of groundwater level occurs in August almost coinciding with the peak of rainfall. The groundwater level fluctuations during the rainy season varies from 1 foot at the higher elevations to

8 feet near the valley. These fluctuations were measured above the dry season level. The recession of the water-table levels occurs rapidly after the rains in September.

(ii) Dry season pattern

During the dry season, the vegetation is sparse which reduces evaporation from the deeper layers of the soil profile. As such there is little change in groundwater level throughout the dry season.

2.4 Groundwater contours

Contours are prepared by interpolation at 50 feet vertical interval using the dry season water table levels - see Map II. The contours are used for the following interpretations:

(i) The groundwater forms a widespread sheet or water-table which is gently undulating rather than horizontal and follows, to some degree, the ground topography. The average dry season water-table gradient is approximately 1.0 per cent.

(ii) The groundwater contours present positive evidence that there are no barriers as there is continuity in

the water-table. The particle size distribution curve Fig.II(a) is typical of soils below the water-table in wells on the banks of the river.

(iii) The contours show the areas of effluent and influent seepage. Effluent seepage takes place where the contours are bent upstream and influent seepage downstream. Comparison of the surface and groundwater contours indicates the areas of effluent seepage only.

(iv) The direction of movement of groundwater is indicated by the water level gradients, being at right angles to the groundwater contours. As observed (Map II), the groundwater flow is towards the river, that is to say that the most economic way of withdrawing the ground-water economic way of withdrawing the groundwater is by excavations in the dry river bed.

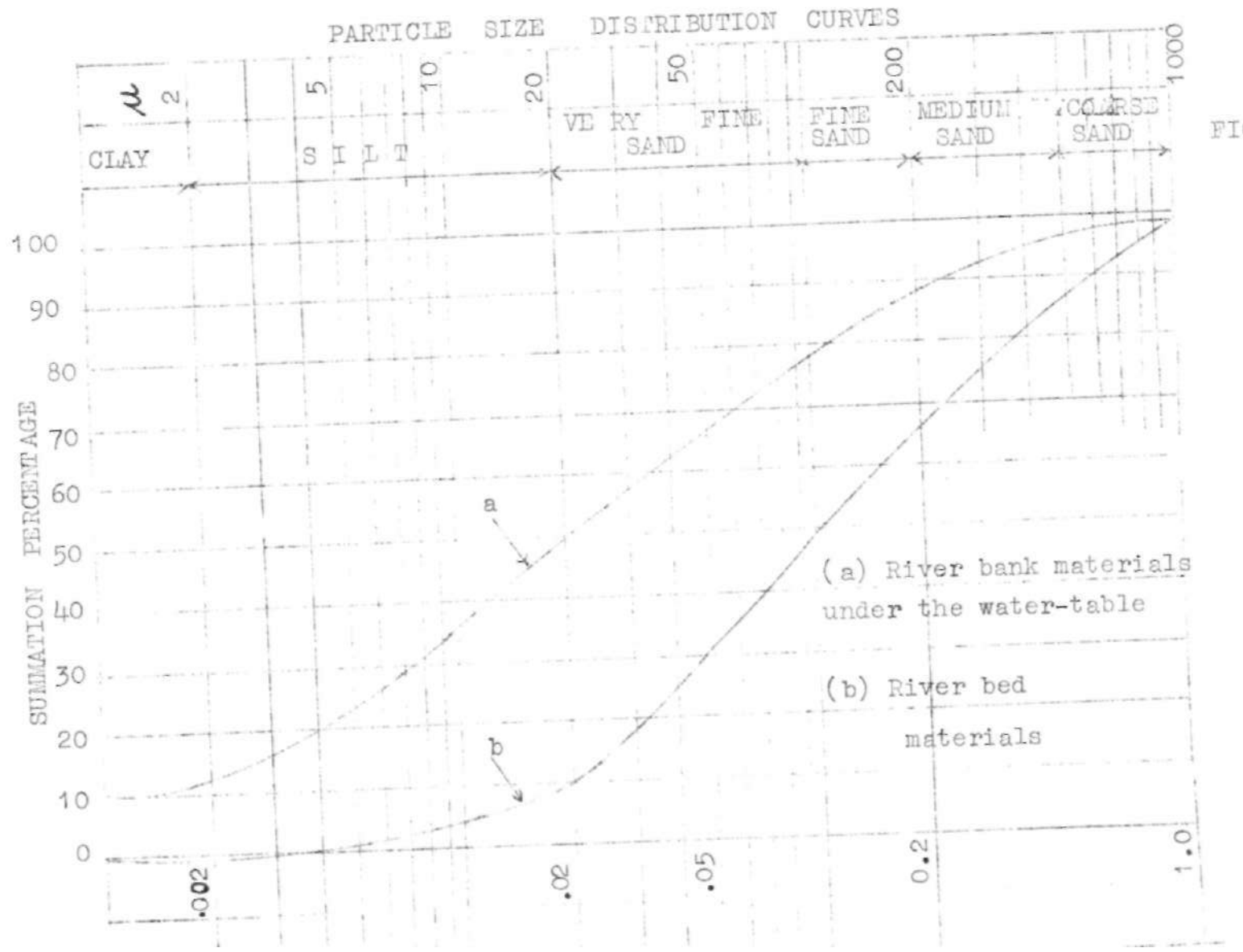

PARTICLE SIZE DISTRIBUTION CURVES
μ
2
5
10
20
50
200
1000
CLAY
SILT
VERY FINE SAND
FINE SAND
MEDIUM SAND
COARSE SAND
SUMMATION PERCENTAGE
100
90
80
70
60
50
40
30
20
10
0
.002
.02
.05
0.2
1.0
a
b
(a) River bank materials under the water-table
(b) River bed materials

FIG. I

PART III

DELINEATING SUITABLE AREAS FOR IRRIGATED AGRICULTURE

3.1 Introduction

The principal role of the soil is not only as a foothold for man and animals and their dwellings but also as a support for plant structure and as a source of supply of nutrients and water for plant growth.

The geomorphology of the soil units on the higher elevations is complex owing to various ironpan formations. Its upper layers are fine grained containing about 60 per cent of fine sand. In addition the land surface contains many local slope irregularities in various directions. The cost of bringing this area under irrigation is prohibitive as heavy land development needing heavy earth moving machinery would be involved.

The plateau along the banks of the river contains fairly uniform slopes towards the river. This strip of land 100-1600 feet wide is occasionally interrupted by gorges which act as natural drainage channels. For

this study the irrigated agricultural sites are confined to the plateau strip.

The primary motive, in evaluating the possibility of irrigating the land is to assess its capacity to withstand intensive irrigation without any deterioration and secondly to assess its perpetual productivity. The suitability of the soil for intensive irrigated agriculture was assessed using a simple comprehensive system, based on five important factors namely:

i) the soil water holding capacity
ii) depth to water-table
iii) permeability
iv) soluble salt content
v) exchangeable sodium percentage

All the five factors may be grouped together as the physical and chemical properties of the soil.

3.2 Physical and chemical properties of the soil

(i) Soil water holding capacity:

In designing an irrigation system the engineer needs to know how much of the water in a soil is available to plants. Water retention in the soil is a

function of the pore size distribution of the soil, and may be treated as a capillary phenomenon, involving pressure deficiency over a range of suction of main interest in agriculture, i.e., between the field capacity and the permanent wilting point. The pressure deficiency constitute a force capable of sucking water into unsaturated soil - measured in atmospheres.

Field capacity is defined as the moisture content of a deep, permeable, well drained soil several days after a deep wetting - Israelson (1967). As defined, it is a point on a time drainage curve, i.e., it is not an equilibrium point but the moisture content retained for an arbitrary time following irrigation. As there is no satisfactory laboratory method for estimating field capacity, the moisture equivalent technique is usually used as an educated guess for estimating field capacity of the soil. For all practical purposes pF 2.0 corresponds to the field capacity of the soil.

When the soil moisture available to plants is exhausted, they wilt and the permanent wilting point is reached when the plants do not recover turgidity when

placed in a humid atmosphere. The permanent wilting point is widely used in irrigation farming to represent the lower limit of water available to the crop. This limit is usually measured by the tensiometer, as it is the only tool available for measuring suction directly on the field. 15 atmospheres or pF 4.2 is the pressure which corresponds to the permanent wilting point.

The available water for plant growth is the capillary water between field capacity and the permanent wilting point. Hence the available water holding capacity of the soil is usually determined by subtracting the amount of water remaining in the soil at the permanent wilting point from the amount held at field capacity. This helps in determining the number of days that can be allowed for applying irrigation water and hence is one basis for capacity and equipment design.

(ii) Depth to water-table

Water-logged land occurs as a result of the rise of the water-table which is due mainly to the inflow of water in the soil by infiltration and the presence of a heavily compacted soil or a clay sub-stratum, which

does not allow easy natural drainage. A high water-table within the root zone is harmful to plants as aeration of the plant actually ceases and the soil may become saline. For most irrigated crops the root depths are usually not more than 4 feet and the soil with this depth must not be heavily compacted as this restricts the root development and penetration. The degree of soil compaction is indicated by the total porosity percentage which represents the soil space occupied jointly by water and air and is usually determined using the values of particle density and the bulk density of the soil layers.

(iii) Permeability and infiltration rate

Permeability is important with respect to soil and water management as it is measure of the ease with which water percolates through the soil mass and may be evaluated by observing the soil profile and by rapid estimation of texture. The infiltration rate of water into the soil depends on whether the soil is permeable or not.

Infiltration rates are important in irrigation

practice because by establishes the rate at which water should be applied to the land and the time interval between application. A common procedure for its estimation is the use of two concentric cylinders with the outer cylinder serving as a guard to reduce lateral water movement through the soil below the cylinders. The unit of measurement may be expressed in inches per hour.

(iv) Soluble salt content

The soluble salt content of the soil determines whether the soil is to be classified as ei either acidic or alkaline and determines the pH value of the soil. Its value depends upon the amount of ionized or dissociated salts in the soil and its value for a solution is a measure of the hydrogen ion (H^+) concentration. It is the Numerical value of the negative power to which 10 must be raised in order to express the required H^+ concentration, or in other words pH is the logarithm of the reciprocal of the H^+ concentration Electrometric methods are widely employed for the determination of pH value.

The scale of measurement is as shown in pH scale

TABLE II

$H^+ - 10^{-0}, 10^{-1}, 10^{-2}, 10^{-6}$ pH - 0, 1, 2, 6	Acid soil
$H^+ - 10^{-7}$ pH - 7,	Neutral soil
$H^+ - 10^{-8}, 10^{-9}, 10^{-10}, 10^{-14}$ pH - 8, 9, 10, 14	Alkaline soil

v) Exchangeable sodium percentage

Sodium, magnesium, calcium and potasium are the important cations in the soil, as large amounts of food material for the use of plants resides in the cations. The clay soil behaves as charge ion and the exchangeable cation viz Na, Ca, Mg, K and hydrogen are in combination with the clay. Cation exchange capacity of the soil is of prime importance in all studies of the relationship between soil conditions and plant growth as it refers to the ability of the soil to combine with bases in such a manner that it cannot be easily removed by simple leaching with water but they

can be readily exchanged by an equivalent amount of other bases. Exchangeable cations and exchangeable cation capacity are determined by chemical methods as adopted by the Salinity Laboratory California.

Exchangeable sodium percent (ESP) which is the degree of saturation of the soil exchange complex with sodium is calculated as follows:

$$E.S.P. = \frac{\text{Exchangeable sodium (meq./100gm soil)}}{\text{Cation exchange capacity (meq/100gm soil)}} \times 100 \quad \ldots\ldots\ldots\ldots\ldots 3(1)$$

3.3 Experimental sites

Six sites were randomly chosen in the study area as potential irrigation areas - 3 sites on each bank. A number of soil samples were taken at each site, i.e.

(i) A 4 feet square by 6 feet deep pit was excavated on each site.

(ii) To determine bulk density, particle density and pF determination, undisturbed samples were taken using a 100 cm^3 steel hollow cylinders. For mechanical and chemical analysis, disturbed samples in required quantities were taken in polythene bags. The depth to water-table on each site was continued using a 4 inch

auger.

3.4 Laboratory analyses

The chemical and physical analysis were carried out following the procedures of Salinity Laboratory Agricultural Handbook No 60 U.S. Department of Agriculture.

(i) Particle size distribution

Bouyoucus method (Hydrometer) was used in the mechanical analysis for the determination of particle size distribution. For the necessary chemical dispersion of the soil-"Calgon" - Sodium hexameta phosphate $(NaPO_4)_n Na_2O$ ' was used as the dispersion agent.

(ii) Pore size distribution

The procedure described by Varder Harst and Stockman using a sand tension table was followed to determine the water content a suction pressure at pF 0.4, 1.0, 1.5, 2.0. Water content at pF 4.0 was determined using a "15 bar" ceramic plate extractor. The water content at pF 4.2 was determined by a pressure membrane apparatus with two layers of cellophane type 'PT 600' and 2mm soil sample. pF is the logarithm of the length

in cm. of a vertical column of water - 1000cm high being 1 atmosphere.

(iii) Bulk density

This was measured using the core method with 100 cm^3 cylinders.

(iv) Particle density

The standard panchrometer method was employed under a controlled temperature using kerosene as the displacing liquid. Under this condition, the density of kerosene was kept constant.

(v) Permeability

This was determined using a ring infiltrometer. The two concentric pipes are 9 inches and 14 inches in diameter. The external ring was primarily used to confine the flow underneath the central pipe to a one-dimensional flow on which all measurements were made. Both cylinders were jacked into the soil 8 inches deep.

3.5 Analysis of results

(i) Available water holding capacity

The available water can be calculated in a soil if the moisture content percentage at various tensions at

different depths are known. These are shown in Table III. The laboratory results for the soil samples taken from the six pits are similar in each type of test and the values shown in Tables III.are therefore the average results. Table IV shows the physical properties of the soil at different depths.

For irrigation, moisture content is usually expressed in inches of water per foot depth of soil instead of percentage by weight. The moisture content per foot of depth on volumetric basis is shown in Table V. It is observed that the available moisture holding capacity in inches of water per foot depth of the soil increases with the soil depth up to the root zone. For this type of soil which is fine texture sandy clay the U.S.D.A. gives the water holding capacity as between 1.60-2.50 inches per foot depth of the soil. Evidently the water holding capacity of the soils under consideration is acceptable.

(ii) Depth to water-table

The depth of the water-table varies from place to place across the plateau. In general, as measured

during the dry months (Oct-April), it was 9 feet and 22 feet deep at distances 50 feet and 450 feet respectively away from the river banks.

The soil below the water-table was analysed for particle size distribution and the results are plotted in Fig II. They compare favourably with that of the sand in the river bed Fig II which is very permeable. It can be concluded that the water-table condition on the plateau is excellent.

(iii) Permeability

The permeability of the soil varies from place to place, usually it is of the range of 0.5 to 2 inches per hour. However, the rate is within the accepted limits for this type of soils in accordance with the U.S.D.A. classification. Hence the permeability of the soil may be classified as good.

(iv) Soluble salt content

The chemical properties of the soil are as shown in Table VI which is slightly acidic as the pH is less than 7. A pH value in excess of 8.5 is undesirable on account of alkali hazzards whilst a pH value less than

4.5 is undesirable as availability of nutrients to crops becomes a limiting factor.

The soil may be considered as excellent as the pH values are within the two limits. However the use of fertilizers and biological manure can improve the fertility of the land and still be an economic proposition.

(v) Exchangeable sodium percent

Using expression 3.1 and the data in Table VI the extreme value of the exchangeable sodium percentage is approximately 5.0. Soils for which the exchangeable sodium percentage is greater than 15 are known as sodic soils. In sodic soils soil structure breaks down and eventually the soil colloids are dispersed, resulting in a rubbery condition and reduction of permeability.

The soil is saline as the value of the exchangeable sodium percent is less than 15. To improve the soil condition it is necessary to establish an adequate drainage system and the soluble salts are removed by leaching. The exchangeable sodium percentage is classified as good.

3.6 Rating the land for irrigation

One method of rating the land for irrigation based on organise and synthesize facts concerning the physical and chemical characteristics of the soil equated to an economic parameter in a given climatic setting is given by the expression - Hagan (1967)

$$E = f(S,T,D) \quad \ldots\ldots\ldots 3.2$$

where E is economic parameter,

S is soil characteristics

T is topographic characteristics

D is drainage characteristics

The system is satisfactory but suffers from a serious defect in that adequate consideration is not given to a limiting role played by a single factor which may sometimes render the soil unsuitable for irrigation.

It is therefore suggested that irrigation lands be classified as excellent, good, fair or poor and that each of these corresponds to 3, 2, 1 or 0 marks respectively. After this marking, the scores of the five characteristics are multiplied together to arrive at the final score i.e., (A x B xC x D x E) in Table VII

On the basis of this score, the classes in Table VIII are suggested for the final rating.

Thus, a soil having good water holding capacity, permeability and low water-table and low exchangeable sodium percentage, but high soluble salt content will score zero - and will go in class V. Any single limiting factor will thus render the soil unsuitable for irrigation, except if reclaimed.

The score for the soil under consideration is 72 hence it is rated as good for irrigation, as it is a class II soil.

TABLE III

Moisture content in percentage by weight at various tensions

Depth in feet	Soil moisture % at pF of					
	0.4	1.0	1.5	2.0	4.0	4.2
0-1	28.0	27.50	21.40	17.30	12.56	11.20
1-2	28.8	27.74	24.21	20.20	11.87	10.34
2-3	28.3	27.43	23.31	19.91	10.24	9.86
3-4	30.3	29.20	24.1	20.62	10.99	9.86
4-5	27.5	27.12	22.30	19.93	11.02	10.02
5-6	24.7	23.71	20.21	18.24	10.33	9.35

TABLE IV

Physical and hydrological properties of the soil

Depth in feet	Mechanical analysis				Total porosity percentage
	% clay	% silt	% fine sand	% coarse sand	
0-1	20	10	65	5	43
1-2	29	12	52	7	47.5
2-4	16	11	51	22	45.5
4-6	16	10	53	21	40

TABLE V

Available moisture per depth of soil (Volumetric)

Depth in feet	available moisture in inches	Remarks
0-1	1.11	Zone of root penetration and developments
1-2	1.66	
2-3	1.74	
3-4	2.19	Limit of root penetration
4-5	1.90	
5-6	1.71	

TABLE VI

Average chemical properties of the soil

Depth in feet	H_2O	Cacl	Organ carbon %	Base exchange					Sat.
				Na	K	Ca+ Mg	To- tal	CEC soil	
0-1	6.4	5.3	0.90	0.58	0.17	2.90	3.65	7.1	51
1-2	6.4	5.0	0.33	0.38	0.12	2.58	3.08	6.1	51
2-3	6.2	4.9	0.17	0.60	0.24	3.69	4.80	9.4	51
3-4	6.5	5.5	0.05	0.58	0.11	2.04	2.73	3.7	74
4-5	6.5	4.9	0.04	0.10	0.12	2.80	3.02	5.8	52
5-6	6.5	4.8	0.03	0.08	0.13	2.80	3.01	5.1	59

TABLE VII

Score card for rating of land for irrigation

Description	available water holding capacity	permeability	depth to water table	soluble salt con content	exchangeable sodium percentage
	A	B	C	D	E
excellent	3	3	3	3	3
good	2	2	2	2	2
fair	1	1	1	1	1
poor	0	0	0	0	0

TABLE VIII

Land rating standard

Class	Description	Score
I	Excellent	Above 80
II	Good	50-80
III	Fair	16-49
IV	Poor	2-15
V	Unsuitable	0-1

PART IV

QUANTITY OF THE GROUNDWATER FROM SHALLOW EXCAVATION IN THE RIVER BED

4.1 Introduction

Of the renewable natural resources, the most important asset with the maximum impact on the life and welfare of people, is water and is an indispensable element in agricultural production. It is not only needed for plant growth and evapotranspiration but also for initial irrigation applications for soil preparation, for fertilizing processes and for the reduction or prevention of excessive salt accumulation in the soil.

Water for all purposes is provided by nature in the form of precipitation, the occurrence and distribution of which varies widely both spatially and temporarilly. In the area of study the dry season is prolonged and this necessitates the exploration and exploitation of the groundwater accumulated during the rainy season.

Many workers have carried out investigation to obtain solutions to groundwater flow problems by establishing relationships governing the flow of water in a porous soil. Some of the early workers are Darcy (1856)

Dupuit (1863), Hazen (1892), and Slichter (1899).

The recent investigators include Theim (1905) Theis (1935) Muskat (1937) Chow (1952), Hantush (1962) and Brooks (1966). These workers have advanced methods of solutions to various flow problems, mostly on confined aquifers.

Owing to the complexity of groundwater occurence, each area needs specific treatment along some well chosen guide lines already established but the most important single characteristic of a soil that influences the flow of water through it, is permeability.

4.2 Permeability

Permeability refers to the facility with which water moves through a porous media, and this movement is immensely complicated as it is controlled by the number, size, shape, total volume and degree of interconnections of the voids of the transmitting medium. These pore parameters are very difficult to measure and usually some indirect form of determination is needed.

Permeability test of soils are quite simple in theory and are usually based on Darcy's law which in-

dicates that there is a linear dependence of seepage velocity upon the groundwater slope. Consider the groundwater flow in the river between Sections I and II in diagram I. As the groundwater is non-viscous and incompressible Bernoullis equation may be applied to the sections that is

$$Z_1 + \frac{p_1}{w} + \frac{v_1^2}{2g} = Z_2 + \frac{p_2}{w} + \frac{v_2^2}{2g} + \Delta y \quad \ldots\ldots\ldots 4(1)$$

where Δy is the total head loss (energy per unit weight of fluid) of the water over the distance L

$\frac{p}{w}$ is the pressure head

Z is the height of the position considered above some datum.

$\frac{v^2}{2g}$ is the kinetic energy

L is the distance between the sections

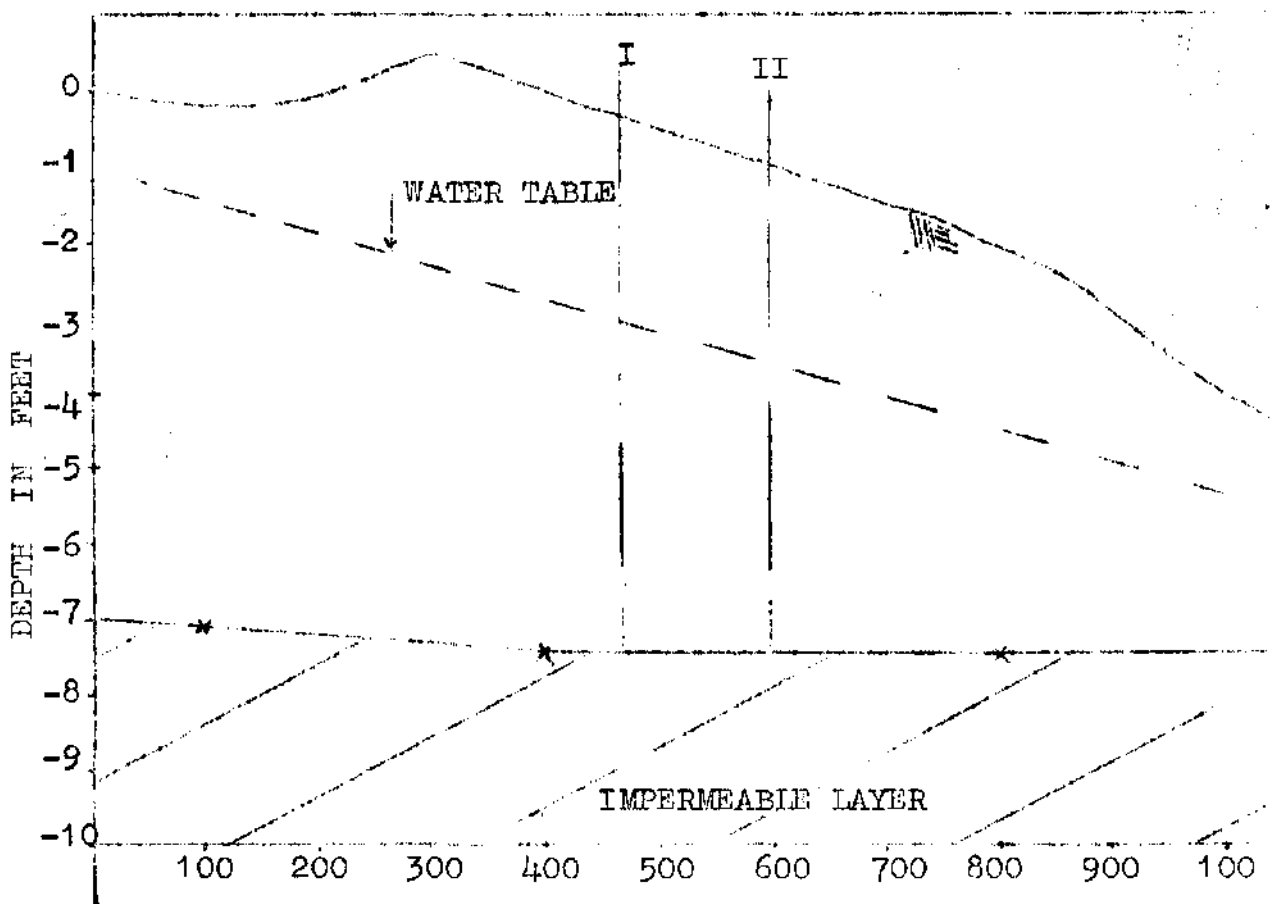
The velocity is small and the square term may be neglected hence equation 4.1 can be written as

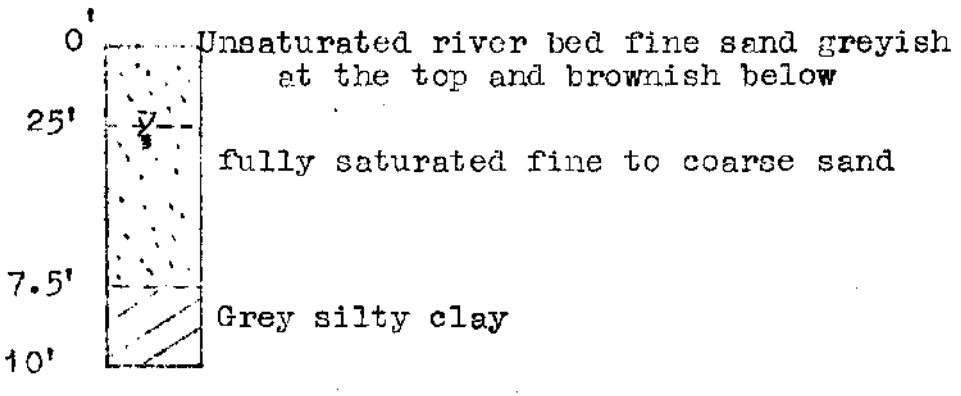
$$\Delta y = (\frac{p_1}{w} + z_1) - (\frac{p_2}{w} + z_2) \quad \ldots\ldots\ldots 4(2)$$

and the total head at any point within the region of flow is simply

$$y = \frac{p}{w} + z \quad \ldots\ldots\ldots 4(3)$$

TYPICAL LONGITUDINAL SECTION OF THE RIVER BED TO IMPERMEABLE LAYER





BORE HOLE LOG AT L.D. 400

Bore logs at L.D 100, 200, shows similar river bed materials

This shows that the head loss is independent of the inclination of the transmitting medium.

Darcy (1856) showed that the relationships

$Q \propto y$ and $Q \propto \frac{1}{L}$ exist

$$Q = - KA \frac{\Delta Y}{L} \quad \ldots\ldots\ldots\ldots \quad 4(4)$$

where Q is the discharge quantity

k is a proportionality constant known as the coefficient of permeability and has the dimensions of velocity L/T

A is the flow area at right angles to the flow direction.

The negative sign indicates that the flow is in the direction of decreasing head.

The ratio

$$\lim_{L \to 0} \frac{\Delta Y}{L} = \frac{dl}{dL} = i \quad \ldots\ldots\ldots\ldots \quad 4(5)$$

is called the hyraulic gradient and represents the space rate of energy dissipation per unit weight of the water flowing a dimensionless quantity

Equation 4(4)can be written as

$$Q = - kiA \quad \ldots\ldots\ldots\ldots \quad 4(6)$$

4.3 Conditions for the determination of k

In determining the permeability of the sandy bed, one of the more important factors to be considered is the structural arrangement of the soil which is likely to be disturbed while it is being sampled and transported to the laboratory and placed in the permeameter. In most cases the samples are small and may not be representative of the entire porous stratum in question. Hence a field test technique was used in determing the k where the region of influence on the test is not only significantly larger than the laboratory sample but is also more indicative of the overall"in situ" behaviour of the soil.

A field test for this property requires a measure of the movement of water which can be accomplished as follows:

(i) withdrawing water from a saturated soil while observing the drawdown carve

(ii) discharging water into the soil stratum i.e. by an infiltration test.

Method: (i) is rather costly to practise as it involves

a specially constructed well with screening and gravel packing as well as two to four observation wells and is mostly suitable for deep wells.

Method: (ii) is not only cheaper to carry out but has a wider range of applicability than method (i). Many formulae have been evolved by the U.S. Bureau of Reclamation (1960) to determine k, using method (ii).

4.4 Set up for the determination of k

The coefficient of permeability k was determined using method (ii) where the rate of infiltration was determined in a cased hole below the water-table as a function of time. Twenty sites were selected at random on the river bed for the test.

In each test a 4 feet length of 6 inch diameter pipe was jacked downwards into the soil so that at least a two foot length is below the groundwater table. The soil contest in the pipe was removed using a 4 inch diameter auger. The rates of infiltration were observed using a stop watch.

4.5 Results

(i) River bed materials

A sandy series is found in the river bed consisting of fine and coarse sand with concretions of line. The grain size of this sand varies from 20 microns to 1,000 microns, but sometimes particles are found with diameters from 1,500-2,000 microns. The very top layers of sand are believed to be wind blown, as studies indicated their aeolian character.

At the base of the sandy layer at a depth of approximately 7 feet or 5.5 feet below the groundwater table in the river bed, a silt clay is found. This impervious layer can be considered to be the impervious basement which probably extends under the entire river course. The particle size distribution, curve of the saturated river bed material is shown in Fig. IIb.

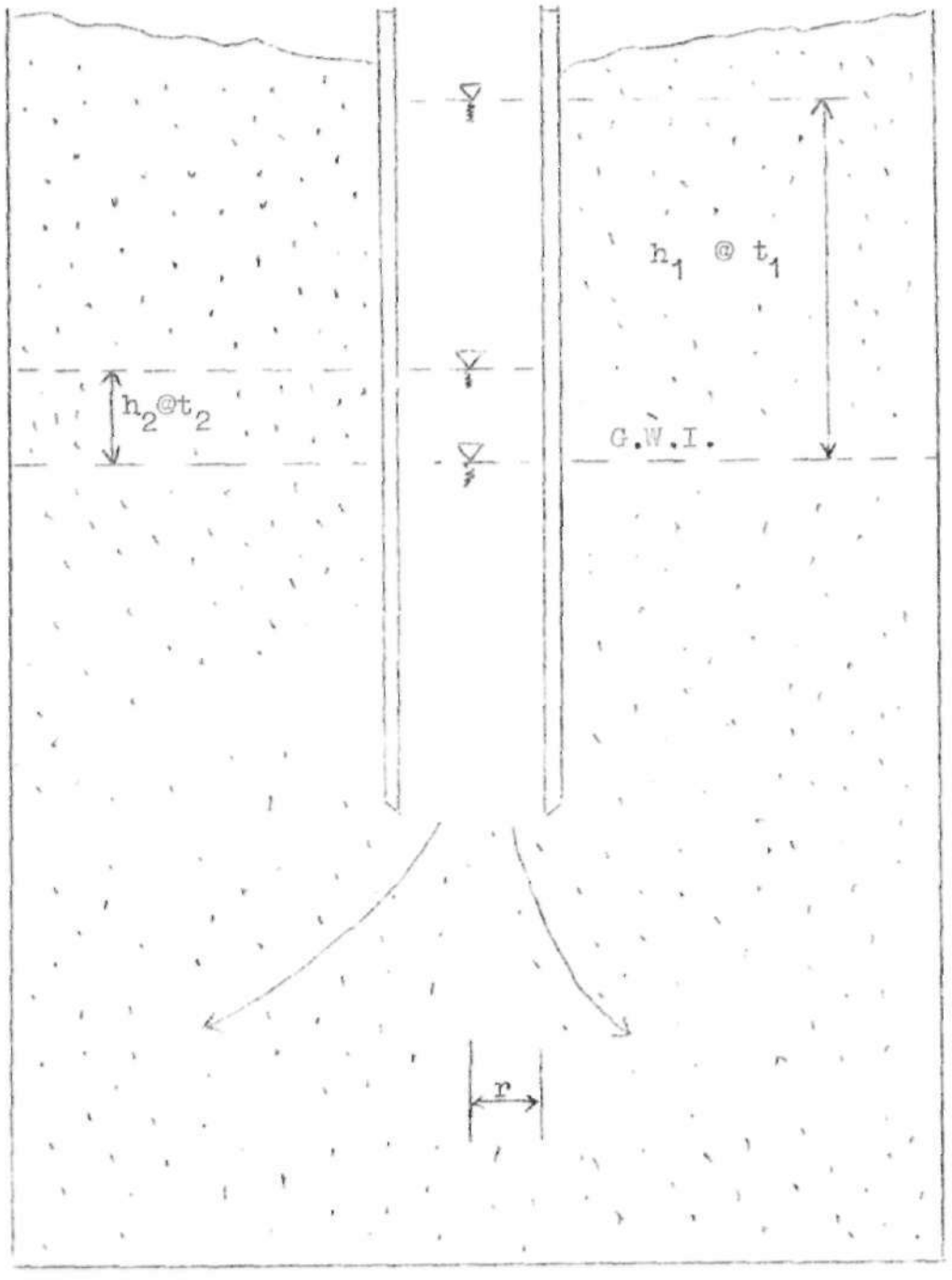
(ii) Development of a theoretical relationship for k

In this analysis the bottom of the pit is assumed to be a point source from which there is a spherical flow in all directions, and the soil is homogenenuous and isotropic, diagram II

At the time interval dt as the water level falls in the pipe through the distance dh the discharge dQ

DIAGRAM II

THE DETERMINATION OF PERMEABILITY



taking place

$$dQ = \pi r^2 \frac{dh}{dt} = -4\pi r_1^2 k\, i \text{ (equation 4.6)} \quad \ldots 4(7)$$

where r is radius of pipe

r_1 is radius of spherical flow area

i is the hydraulic gradient

if we let dt become infinistesimal, integrating equation 4.7 and introducing the initial conditions viz, at $t = t$, $h = h1$, $r = r_1$, etc

we obtain:

$$k \frac{4r_1}{r^2} (t_2 - t_1) = \ln \frac{h2}{h1} \quad \ldots\ldots\ldots 4(8)$$

Expressed in the system of decimal logarithms,

$$k = \frac{2.3r}{4T} \log_{10} \frac{h2}{h1} \quad \ldots\ldots 4(9)$$

where T is $(t_2 - t_1)$

Three tests were performed in each station at an average time interval of 3 minutes. The results were analysed statiscally as shown in Appendix II and the coefficient of permeability of the sand was averagely 1.80 feet per hour. Using the standard expression due to the U.S. Bureau of Reclamation (1960) the permeability is 1.65 feet per hour which differs from the

previous result by only 8% but this is to be expected as the Bureau's formula was derived for similar materials but in another part of the world.

4.6 Potential yield from the excavation

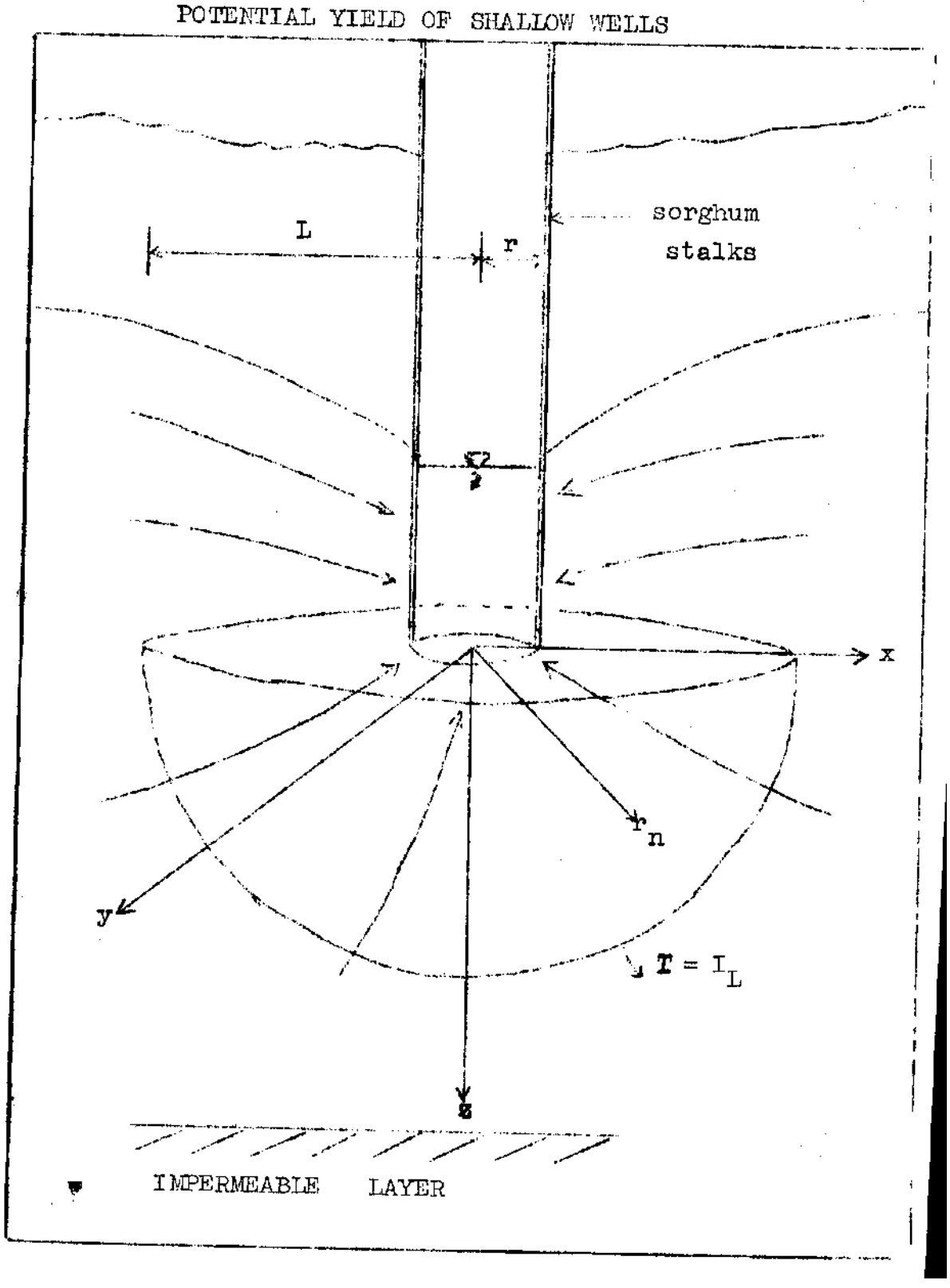
Seepage quantities under dams, sheet piles, and through irrigation embarkments may be determined using a flow net and two dimensional flow techniques; if the permeability of the material is known - Todd (1959), Harr (1962) and Polubarinova-Kochina (1962). The flow of water into a well, of any geometrical shape when partially penetrating the aquifer is however three dimensional in character, which implies that the problem cannot be adequately resolved by means of flow net techniques but an analytical approach provides a sound basis for the determination of the theoretical yield.

(ii) Partially penetrating well

Small scale excavations can be considered as partially penetrating free aquifer wells of various geometrical shapes. Consider the well shown in diagram III then the Laplace velocity potential equation is

DIAGRAM III

POTENTIAL YIELD OF SHALLOW WELLS



$$\frac{d^2I}{dX^2} + \frac{d^2I}{dy^2} + \frac{d^2I}{dz^2} = 0 \quad \ldots\ldots\ldots\ldots \quad 4(10)$$

where I is the velocity potential and

x, y, z are rectangular Cartesian coordinates.

Since the flow into such a well is spherical it is preferable to express the above equation in spherical coordinates (r, θ, X)

$$\frac{1}{r^2}\frac{d}{dr}\left(r^2 \frac{dI}{dr}\right) + \frac{1}{r^2 \sin\theta}\frac{d}{d\theta}\left(\sin\theta \frac{dI}{d\theta}\right) + \frac{1}{r^2 \sin^2\theta}\frac{d^2I}{dX^2} = 0 \quad \ldots\ldots\ldots \quad (4(11)$$

As the fluid system possesses spherical symmetry, the symmetry is expressed by taking the origin of the system at the centre of symmetry which causes the terms $\frac{dI}{d\theta}$ and $\frac{dI}{dx}$ to vanish. Hence equation 4.11 reduces to

$$\frac{1}{r^2}\frac{d}{dr}\left(r^2 \frac{dI}{dr}\right) = 0 \quad \ldots\ldots\ldots\ldots \quad 4(12)$$

From equation 4.12 $r^2 \frac{dI}{dr}$ = constant = c

$$\text{Hence } I = -\frac{c}{r} + c_1 \quad \ldots\ldots\ldots\ldots \quad 4(13)$$

c_1 is a constant due to integration.

Equation 4.13 demonstrates that in the spherical flow

the potential I varies inversely with the radius. The discharge at any radial distance r_n from the origin i.e. centre of the sphere is

$$Q = 4\pi r_n^2 \, Vr_n = 4\pi r_n^2 \, \frac{dI}{dr_n} \quad \ldots\ldots \quad 4(14)$$

where $4\pi r_n^2$ = the surface area of the sphere and

Vr_n = the radial velocity

From equation 4.14 I becomes

$$I = -\frac{Q}{4\pi r_n} + c_1 \quad \text{---------- } 4(15)$$

Note the similarity of equation 4.13 and 4.15

At the well we let $r_n = r_w$ and $I = I_w$

c_1 in equation 4.15 becomes

$$c_1 = I_w + \frac{Q}{4\pi r_w} \quad \ldots\ldots\ldots\ldots \quad 4(16)$$

where r_w = the well radius

I_w = the velocity potential at the well

If we substitute equation 4.16 for c_1 in equation 4.15 we obtain

$$I = \frac{Q}{4\pi}\left(\frac{1}{r_w} - \frac{1}{r_n}\right) + I_w \quad \ldots\ldots\ldots \quad 4(17)$$

Equation 4.17 demonstrates that I varies directly with

the discharge flux. The variation is rapid. Now consider a distance L from the centre of the well as its radius of influence and putting in the initial boundary condition as

$$I = I_{r_n} \quad \text{where } r_n = r_w$$

and $I = I_L$ where $r_n = L$ and rearranging terms in equation 4.17, the total flow Q is

$$Q = \frac{4\pi(I_L - I_w)}{\frac{1}{r_w} - \frac{1}{L}} \quad \ldots\ldots\ldots \quad 4(18)$$

Under natural conditions $\frac{1}{r_w} >> \frac{1}{L}$

$$Q = 4\pi(I_L - I_w)\, r_w \quad \ldots\ldots\ldots \quad 4(19)$$

The discharge into the hemisphere $= Q/2 = Q^1$

$$Q^1 = 2\pi(I_L - I_w)\, r_w \quad \ldots\ldots\ldots \quad 4(20)$$

Equations 4.19 and 4.20 demonstrates that both Q and Q^1 are independent of the extent and shape of the external boundary of flow as $r_w \ll L$ and as such the detailed geometrical shape of the well and its external flow boundary may be considered as of little importance.

The main problem in determining Q is in finding the analytical solution to the velocity potential I_L and I_w. However an approximate solution for Q was given by Muskat (1937) as

$$Q = \frac{2\pi h (I_L - I_w)}{(.5\bar{h})\left(2\ln(4h/r_w) - G(\bar{h})\right) - \ln(4h/L)} \quad \cdots\cdots 4(21)$$

where $\bar{h}$ is the well penetration in fraction of the depth of the permeable layer h

$$I_L - I_w = \Delta p k/u \quad \cdots\cdots\cdots 4.22$$

where ΔP is potential drop u is the liquid viscosity, and k is the sand permeability.

Pressure differential is assumed to be 1 atmosphere, therefore k/u = 1

$$G(\bar{h}) = \ln \frac{F(8.875\bar{h})\, F(0.125\bar{h})}{F(1-0.875h)\, F(1-0.125h)} \quad \cdots\cdots 4(23)$$

where F are gamma functions

$G(\bar{h})$ is plotted against h as shown in Fig. III. The values of $G(\bar{h})$ and h are substituted in equation 4.21 to find Q(- Table IX) L being 200 feet.

In this analysis the well is assumed to be cir-

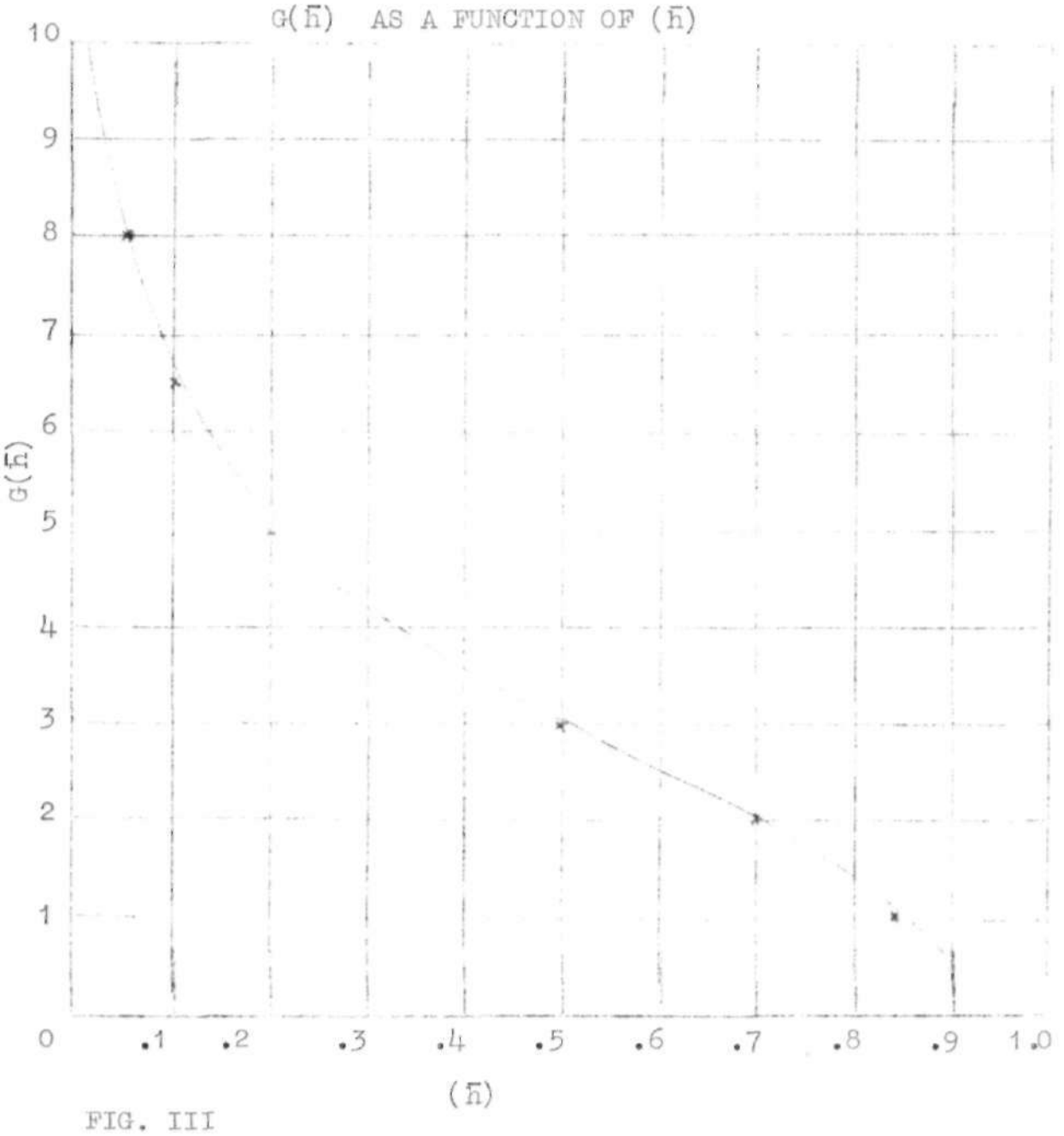


FIG. III

cular. For polygonal shaped wells the average radius of the inscribed and circumscribed circles is considered sufficiently accurate for practical purposes.

TABLE IX

Theoretical discharge per 1 square foot of surface area per depth

Depth in feet	Discharge in gall. per hour
1	910
2	372
3	57

Owing to lack of accurate knowledge of the velocity distribution, air entrained in the soil and non-homogenuity of the water bearing strata, the theoretical analysis cannot predict quantitative results closely and for useful design information one has to rely upon experimental studies.

4.7 Yield by experimental method.

Two experiments were organised in this connection, rectangular wells and circular wells.

4.7 1 Rectangular wells

This method involved a rectangular excavation its dimensions approximately conforming to the traditional form used by the local farmers.

(i) Layout

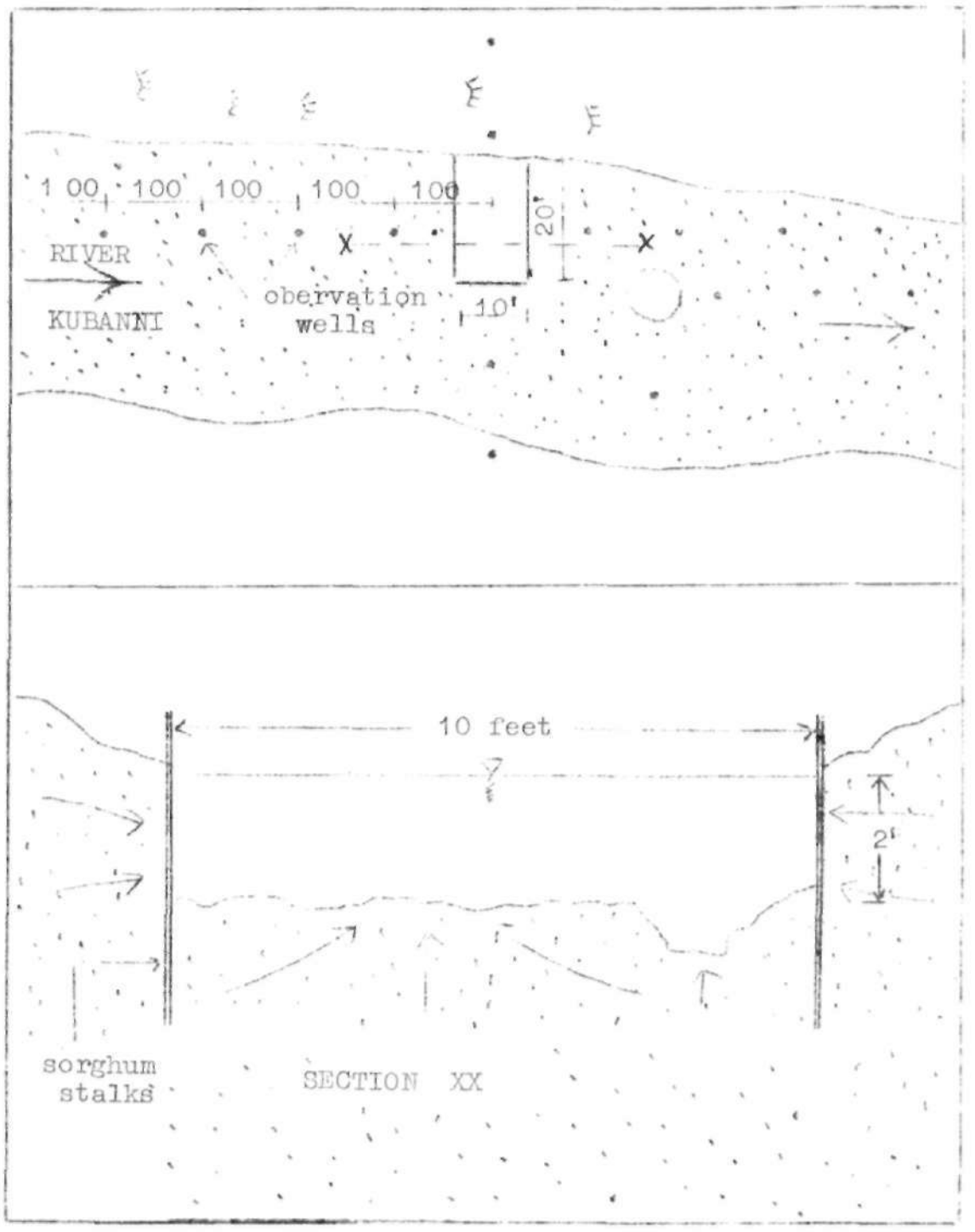
The longer side of the rectangle was perpendicular to the river course, with one side of the shorter sides bounded by the left bank of the river. Observations wells were spaced 30, 100, 200, 400 and 500 feet away on both sides of the excavation - diagram IV.

(ii) Method of construction

At the experimental area (marked X Map II) the water-table was 2.25 feet below the dry bed. The dry sand was removed from the entire surface area of 35 feet by 20 feet. Within this area a 20 feet by 10 feet rectangular section was marked out. Dry sorghum stalks were packed closely and almost vertical round the periphery of the rectangle to act as a retaining wall structure. Excavation was to 24 inches below the water table. Dewatering was carried out using a petrol driven centrifugal pump.

DIAGRAM IV

LAYOUT OF TEST WELLS



(iii) Suitability of the retaining material

Most of the sorghum stalks used were 4 feet long and throughout the dry months most of the stalks retained the earth very well. The use of such material may not be viable as a long term proposition since when the stalks have being immersed for a long while they rot and decay leaving a peaty residue which decreases the permeability of the wall area. However, this effect can be avoided if the stalks are removed each year and replaced. In any case any bed excanation in the river is rapidly silted-up during the floods and unless a permanent protection, rising well above the flood level, is provided the silting-up is inevitable.

(iv) Determination of the safe yield

Safe yield was determined at 12, 15, 20, 24 inches below the groundwater table. The pond was pumped to the required depth at a uniform rate of 2000 gallons per hour. The rate of pumping was determined by timing the flow of pumped water into a metal tank of known volume.

Tests were carried out throughout the dry months

at each depth. Observation wells spaced at 30, 100, 200 feet upstream showed on the average a drawdown of $4\frac{1}{2}$, $1\frac{1}{2}$ and 0 inches respectively whilst at the downstream side, observation wells spaced at 30, 100 and 200 feet showed on the average a drawdown of 5, $1\frac{1}{2}$ and 0 inches respectively.

The pond was allowed to recuperate until the water rose almost to the original level, i.e. pumping was resumed when the water level rose to within $1\frac{1}{2}$ inches of the original level. The rate of recovery is shown in a plot of recovery height against time in Fig. IV

The safe yield was determined as follows

$$Q_1 = \frac{Q}{T_1 + T_2} \quad \ldots\ldots\ldots\ldots \quad 4.24$$

where Q_1 = safe yield

Q = quantity of water pumped out

T_1 = duration of pumping in hours

T_2 = Recuperating duration in hours

Results are as shown in Table X

q = safe yield / per unit square foot area of pond.

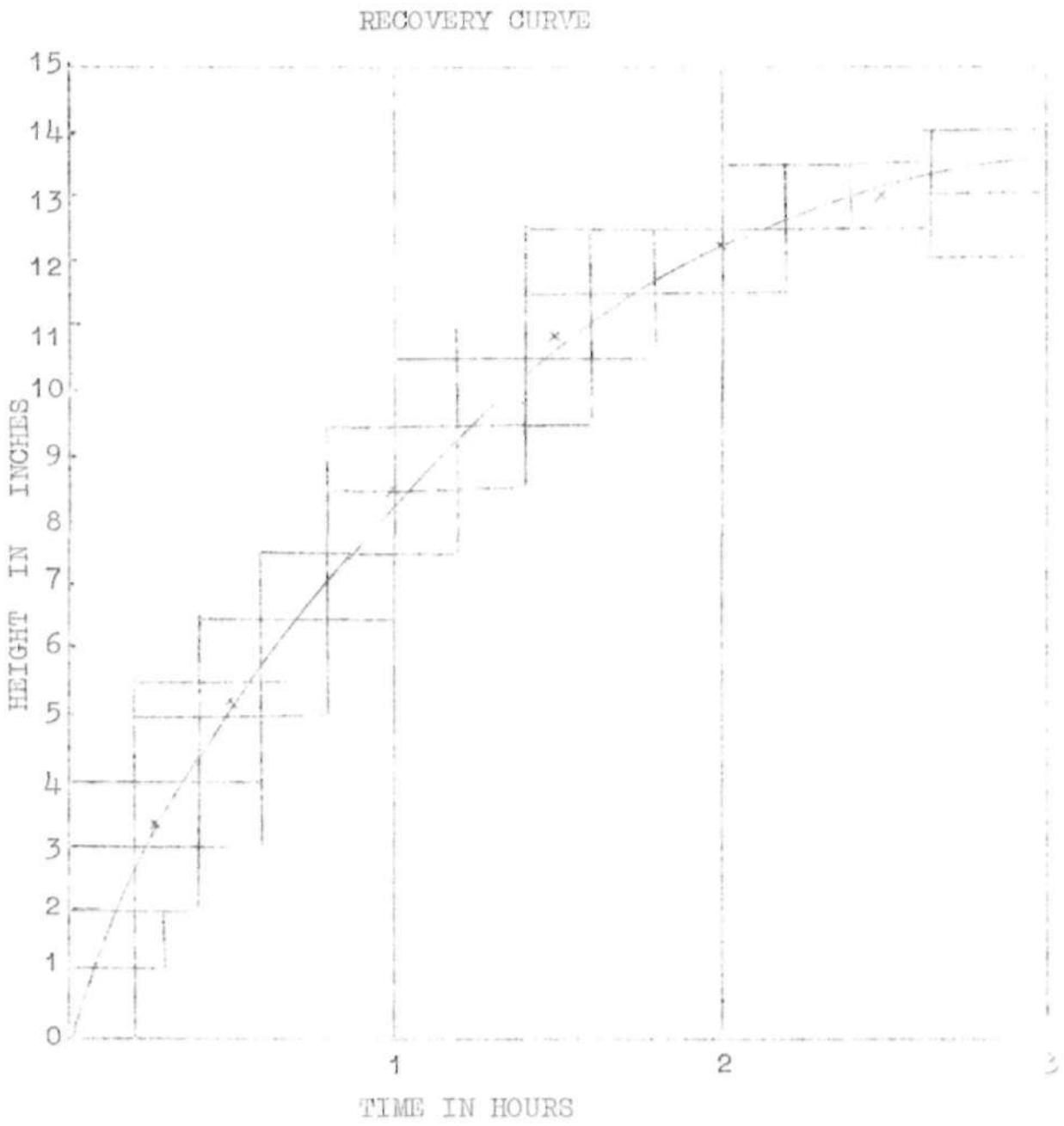

RECOVERY CURVE
HEIGHT IN INCHES
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
1
2
TIME IN HOURS

FIG. IV

TABLE X

Safe yield

Depth	Q_1	q	L radius of influence
Inches	gph	gph	feet
12	880	44	200
15	900	45	200
20	950	47.5	200
24	980	49	200

It is observed from Table X that the increase in the safe yield with depth is not appreciable. There is also a wide gap between the theoretical yield and the safe yield as evident from a comparison of data in Tables IX and X.

Safe yield may be defined as the quantity of water that can be withdrawn from an aquifer in a given time without producing an undesirable effect within the basin, such as 'mining' of the groundwater. As defined safe yield is not a constant quantity as it is subject to considerable variability such as pumping costs and increase in suction head owing to lowering of the ground-

water level.

In order to arrive at a constant daily yield from the pond it is necessary to look into the working period for the farmers as different techniques may be applied to groundwater exploitation. The normal working period for the farmers is usually 6 a.m. to 12 noon for the morning session and 3 p.m. to 6.30 p.m. for the evening session. This is because the unshaded temperature is very high in the afternoons of the dry months when irrigation is practised. Assuming a farmer can efficiently handle 30 to 60 gallons per minute on the farm working for 10 hours a day, and allowing the recuperation to take place during the night, the daily yield is as shown in Table XI and is termed 'Operational yield'. It implies that the yield is dependent upon the pattern of operation of the groundwater use.

TABLE XI

Operational yield per day

Depth in inches below w.t.	Gallons
12	11,000
15	12,500
18	13,500
24	14,600

4.72 Circular well

(i) Layout

This was situated in the middle of the stream course. At this point the water-table was 1.90 feet below the dry bed. The well was lined with precast concrete rings with observation wells arranged much as in Method (4.71)

(ii) Method of construction

Thus 2.75 feet diameter, 1.83 feet deep concrete rings were sunk in the aquifer by excavating the sand content in the cylinders. The diameter is just large enough for a small man to work in it. The loose sand was hauled to the surface in a bucket with a rope.

attached. Two men stood on the rim during the excavation to provide the extra weight required to sink the cylinders. Dewatering was effected using a petrol operated pump. A total depth of 4 feet below the water table was reached. The bottom was packed with a 6 inch thick layer of river gravel

(iii) The determination of well yield

From several tests based on recuperating techniques the well gave a safe yield of 443 gallons per hour. The yield is particularly low for agricultural purposes, however it is adequate for the supply of water for the farmer's herds during the afternoons when he is less busy in his farms.

4.8 Choice of well

The relative merits of the excavation are as shown in Table IV-1. Despite the demerits of rectangular well most of the farmers along the river banks prefer it to the concrete lined well as they are already accustomed to similar excavation in the river bed for their irrigation water and moreover the initial cost of the construction of a concrete lined well of adequate

diameter is not within their financial ability. Consideration is therefore given to the sorghum lined well or 'pond' in the benefit to cost ratio analysis of the project.

TABLE IV-1

Comparison of well construction

Item	Sorghum lining	Concrete lining
Excavation	more earth work is involved hence cost is higher	less earth work and loss cost
Lining material	cheap earth retaining material lining depth is restricted due the material	costly but is within the reach of the average rich farmer. The sand, coarse aggregates, and water are three of the items for the concrete ring construction and are available on site.
Yield	Lower per square foot of seepage area perpendicular to the direction of flow	better than sorghum and further improvement is possible by making the depth of the concrete ring to be 1 foot - especially those that are well below the water table- and the diameter could be increased for storage purposes
Durability	Seasonal and subject to damage by the herds of cattle and floods	permanent structure, the filter material only has be renewed once a year

PART V

THE QUALITY OF THE GROUNDWATER

5.1 Introduction

The various media through which the rain water comes in contact and the rain itself tend to arrive at chemical equilibrium if they are in contact for a sufficient length of time. The major media are:

(i) The atmosphere:- It is here that the water begins to take up carbon-dioxide and to be contaminated by contact with cosmic and industrial dusts and gases.

(ii) The top soil:- Here it finds itself abruptly in contact with soil formations, plants and animal residue.

(iii) The sub soil:- The water forms the principal agent in the decomposition of the rocks.

(iv) The aquifer:- Here the processes of decomposition and dissolution of the enclosing geologic strata continue.

The final chemical composition of underground water determines its quality and the quality standard required depends upon its purposes. Therefore, before actually utilizing the groundwater for irrigation it is

necessary to determine its suitability since the plants may be harmed chemically by metabolic reactions caused by toxic constituents of the groundwater. Evidently the quality of the groundwater is as important as the quantity - Todd (1959) Hagan et al (1967)

5.2 Method of sampling

Samples of groundwater were collected monthly throughout the dry season (October - April) in a screw-cap bottle of 1250 ml volume. Each sample was taken during the recuperation period of the groundwater after pumping from the sorghum line well.

5.3 Method of analysis

All samples were analysed for conductivity, pH, sodium, calcium plus magnesium, chloride, potasium, carbonate and bicarbonate to determine the suitability of the water for irrigation purposes Methods of analysis was as suggested by The Salinity Laboratory procedure Agricultural Handbook No.60 U.S. Department of Agriculture. Chemical analysis were made almost immediate after sampling to prevent any change in the chemical status of the water due to micro-biological activity

which occurs if the sample is stored for a period of time.

5.4 Results: The results are as shown in Table XII

5.5 Assessment of water quality

(i) Conductivity

The electrical conductivity of a solution varies directly with increase in the concentration of the solute, and therefore the total soluble salts can be expressed in terms of electrical conductivity. The soluble salt content helps considerably in estimating the potential saline condition of the irrigated land. The conductivity throughout the dry season (October-May)is between 100 and 200 micro-mho/cm at 25°C. Soils with a conductivity less than 750 micro-mho/cm are reputed to be suitable for irrigation purpose, whereas water samples with conductively greater than 1,600 micro-mho/cm are usually assumed to be totally unfit.

(ii) pH

A hydrogen ion concentration (pH value) less than 7 indicates an acid water. If the pH is higher say up to 8.5, there is the posibility that the CO_3 content

of the water precipitates Calcium and Magnesium of the soil, thereby decreasing the strength of the soluble Calcium and Magnesium and thus promoting an exchange of sodium (the Na) on clay complex. This causes deflocculation and a reduction in permeability. The pH of the water during the period of testing ranged between 6.7 and 7. This is considered suitable for irrigation purposes.

(iii) SAR:- The sodium adsorbtion ration is given by the expression:

$$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}} \quad \ldots\ldots\ldots 5(1)$$

It is an indicator of the effect of relative cation concentration on sodium accumulation in the soil. The cations are calcium, magnesium and sodium with small quantities of potasium. The alkali hazard involved in the use of a water for irrigation purposes is determined by the absolute and relative concentration of its inorganic constituents as they react with soils as ions rather than as molecules. Irrigation water with an SAR value of 0 to 10 is classified as

good and the SAR value of the groundwater under test was less than 1.0 and is therefore most available for irrigation purposes

(iv) Residual sodium carbonate

This is the amount of carbonate or bicarbonate a water would contain after an amount equivalent to the calcium and magnesium has been removed. It indicates the tendency for calcium and magnesium to be precipitated as carbonates in the soil, thereby increasing the ratio of sodium to calcium and magnesium in the soil solution and effectively raising the sodium hazard.

Residual sodium carbonate is given by the expression:

$$\text{Res Na } CO_3 = (CO_3 + HCO_3) - (Ca + Mg) \quad \ldots\ldots\ 5(2)$$

Waters that contain less than 1.25 equivalent parts per million of residual sodium carbonate are assumed safe for irrigation purposes. Values of 1.25 to 2.50 e.p.m. qualify the water as marginal whilst values more than 2.5 is classed as probably unsafe. As the value of the residual sodium carbonate in the water

throughout the period (during the dry months) requiring water for irrigation is less than 1.25 the water is classified as safe and suitable for irrigation purposes.

5.6 Conclusion

There is every indication from the analyses that the water is suitable for irrigation. It may be classified as affording low salinity, sodium, and carbonate precipitation hazards. The quantities of calcium plus magnesium, potasium, and chloride would contribute to crop nutrition. It should be added that it is already used on a very limited scale by local farmers for irrigation purposes.

TABLE XII

The chemical properties of the groundwater

Chemical properties	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APRIL *	MAY
pH	6.9	6.8	6.8	6.7	6.9	7.0	6.7	7.0
Conductivity in micro-mho/c @ 25 c	120	118	100	123	145	100	182	127
Na meq/1.	0.46	0.45	0.42	0.44	0.46	0.39	0.30	0.35
Ca + Mg	0.46	0.46	0.41	0.51	0.70	0.36	1.12	0.54
SAR	0.96	0.96	0.94	0.86	0.78	0.93	0.40	0.68
HCO_3+CO_3	0.57	0.56	0.58	0.88	0.94	0.62	1.64	0.82
R.S.C.	0.15	0.17	0.17	0.37	0.24	0.26	0.52	0.28
K^+	0.09	0.10	0.08	0.16	0.16	0.12	0.25	0.12
CL^-	0.24	0.23	0.23	0.16	0.23	0.15	0.12	0.12
Sediment load gm/lit	0.25	0.24	0.24	0.24	0.21	0.30	0.44	0.35

*There was 0.25 inch of rainfall the night preceeding day the sample was taken.

PART VI

GROUNDWATER LIFTING DEVICES

6.1 Introduction

Nature has provided mankind with water but leaves it to our ingenuity to raise it to satisfy our needs. Through the ages man has tried his best to devise reliable water raising appliances and some of the major developments were caused by the need to provide water for irrigation as evidenced during the early civilization of the Egyptians. The early devices such as the 'shadoof' system and the chain pots were used mostly by the agriculturists in the arid and semi-arid regions of the world and these appliances were developed through tradition and personal experiences rather than by any deliberate design.

Later in the 17th century, the Europeans came into the scene owing to the growing drainage problems in their mining industries and modern mechanically driven pumps have been designed as a result of rapid advances in technology.

6.2 Some conventional pumps

Modern pumping machinery may be primarily divided into the following classes:

(i) Reciprocating pumps

Hand pumps, wind-driven pumps, steam driven pumps may be classified under this heading. The water lifting action of the pumps in general depends on the variation in volume of spaces due to the reciprocating or oscillating motion of one part of the mechanism relative to another fixed part. Parts of such machines include the bucket, the piston and diaphragm. Usually an air chamber is placed in the discharge piping close to the pump to counteract the shock and water hammer caused by the varying rate of discharge of the pump.

(ii) Rotary pumps

The pumping action depends on the variation in volume of a space or spaces due more or less directly to the rotary motion of a part or parts of the pump. There are many varieties but the most common are the vane gear wheel, screw and the rotating-cylinder types. The rotary and the reciprocating pumps are

basically hydrostatic machines.

(iii) Fluid pressure pump - Hydraulic ram:

This is also a hydrostatic machine. Water is raised to high level, in small quantities through the action of large quantities of water under a low head. These pumps require no external power source for their operation.

(iv) Centrifugal pumps

The lifting action is due largely to the liquid being given a rotary motion which produces a centrifugal force and these pumps are classed as rotodynamic machines.

6.3 Other pumping devices

Two water-lifting techniques were investigated in the laboratory and on the field.

6.31 Wick: There are cotton and other porous fibre materials in abundance in Zaria. It would be a good idea if they could be used to lift water for irrigation purposes as the materials are known to be absorbent.

(i) Experimental set up

Highly absorbent cotton wool was arranged in the

laboratory as illustrated in Diagram V with sawdust representing the soil. The "pump" was intially primed by saturating the cotton wool with water.

(ii) Results

After some few days $\frac{3}{4}$ the length of the cotton dried up. The $\frac{1}{4}$ length near the source of supply was fairly wet so was the surrounding saw-dust. The moisture content of the saw-dust was determined and was found capable of sustaining early growth of bean seeds.

(iii) Recommendation

Owing to the layout labour and high inefficiency of this method it is not recommended for the farming practices. However, with a little modification such as replacing the cotton wool with blotting paper it is an ideal device for estimating the consumptive use of water by plants during their early growth.

6.32 Condensation method

The solar system and its connections with the earth may be regarded as a machine. One of the function of the machine is that of circulating the water on its surface. On the average, evaporation from free

DIAGRAM V

LAYOUT OF 'WICK' PUMP

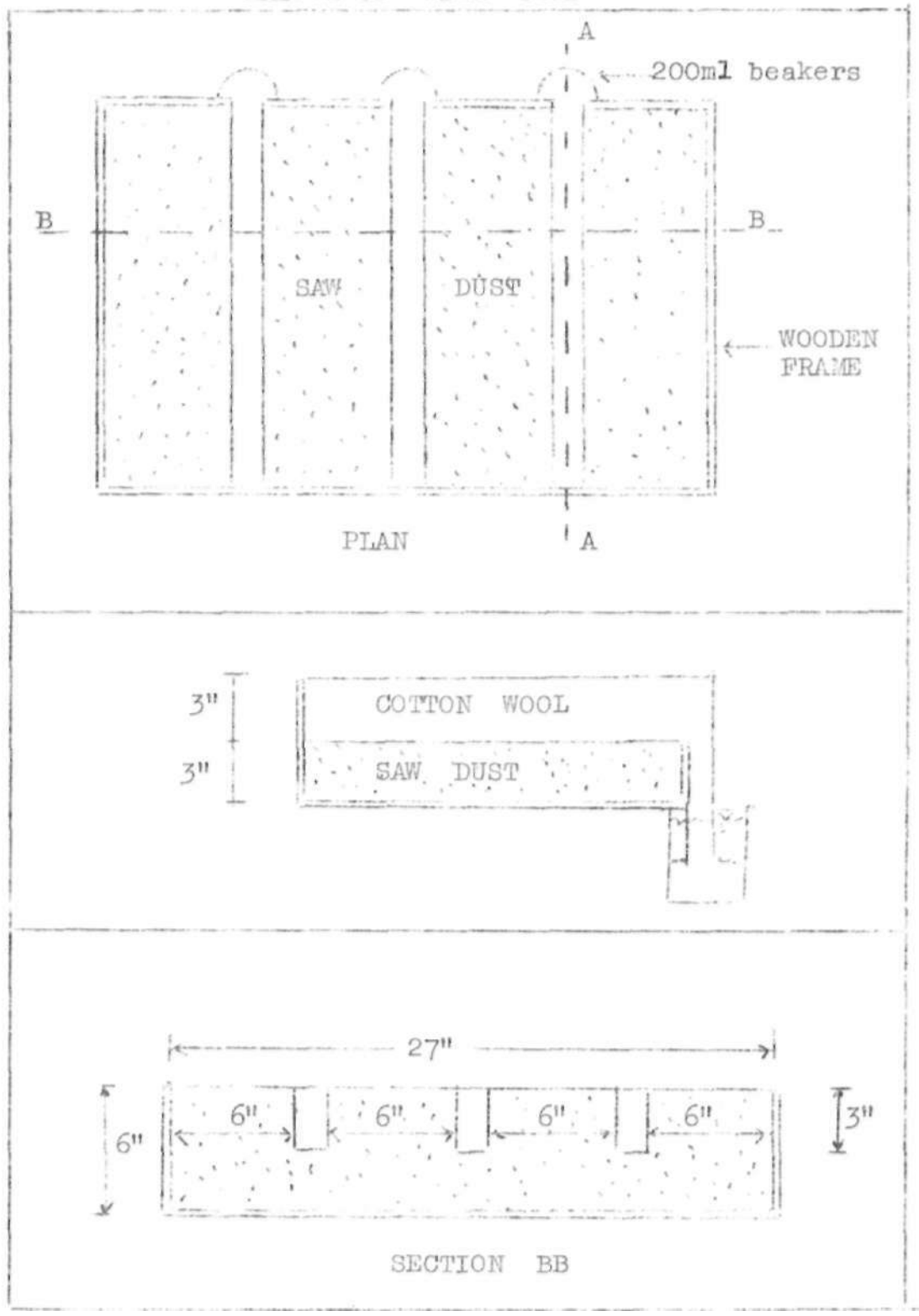
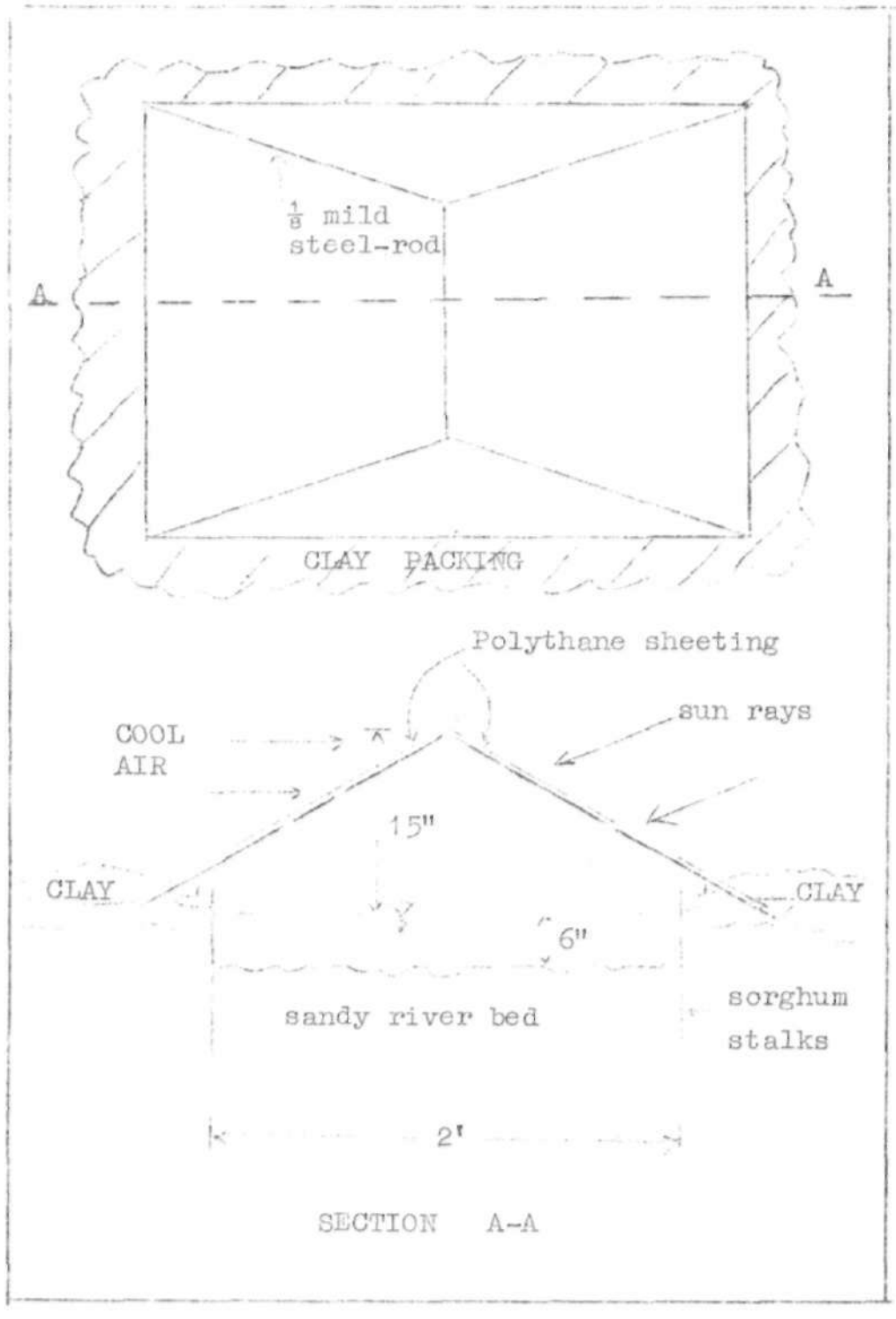


DIAGRAM VI

SMALL SCALE SOLAR STILL



SECTION A-A

water on its surfaces in this part of the world could be as much as 6 feet per year. If interception of evaporated water is artificially possible at the required altitude and right quantity such an endeavour would be one of man's greatest effort in solving the water resources problems.

(i) Experimental set up

The experiment was carried out in the field. A 2 foot square of surface area on the river bed by 3 feet deep was excavated to expose the ground water to a depth of 6 inches. White polythene sheeting and $\frac{1}{8}$ inch diameter mild steel rods were arranged to cover the pit in the manner shown in Diagram VI.

White polythene sheeting is translucent and intercepts the resulting water vapour and condense it into droplets. By this process heat from solar radiation is dissipated to the surroundings while the fresh water condensate may be collected in small channels on each side of the inclined roof.

(ii) Result

The water condensate collected at approximately 2

inches above the water surface was 1050 c.c. per week during the month of April. A large area is therefore required to produce any reasonable amount of such water. The largest solar still in Australia has an area of 38,000 square feet of horticultural glass - the interceptor material-Morse (1968). The cost of fresh water production is almost £1.0.0d per 1000 gallons of water, the production being 30 gallons per square feet per year.

(ii) Recommendation

In Zaria, it is not necessary to have solar stills to supply irrigation water because the water is soft. However, this may solve the water resources problems around the Lake Chad area in Bornu Province, where the soil is fertile but both the lake and the groundwater are too saline for conventional irrigation. Installations of solar stills will go a long way to reduce the saline hazards due to the salt water.

6.4 Choice of pump

The pumping device to be used on the site is expected to be able to pump fairly clean cold water to a

stalic head of some 15 feet inclusive of all frictional losses. The rate of pumping may be put at approximately 40 gallons per minute since the local farmer can handle this quantity without appreciable waste. The normal working periods for the pump would be approximately 8 hours a day. In chosing the right pumping machine, the relative merits of the pumping devices are discussed as follows:

(i) Rotary pumps

Rotary pumps are used where the duty requirements are for small quantities of liquid at medium pressures. They are more suited to handling viscous liquids such as oil rather than water - a free flowing liquid, because flexible packings can rarely be provided to form completely water tight seals between the rubbing surfaces.

(ii) Reciprocating pumps

Reciprocating pumps are used for the high pressure and low quantity discharge. They are complicated, heavy and require large floor area. They have the disadvantage of pulsating flow and as the farmers need

constant flow for good farm management, this is not suitable.

(iii) Hydraulic ram pump

It is an impulse pump which utilizes the momentum of falling water (when a moving column of water is suddenly stopped water harmer is produced) to lift a fraction of the water to a height much greater than that of the supplying source. Water flows down an incline pipe (called drive pipe) whose slope is usually 1:8. The pump in its simplest form is as illustrated in Diagram VII. It consists of a metal box fitted with two automatic non-return valves, working in opposite directions. An air vessel or surge tank surmounts the delivery valve without which the pump has a very low efficiency.

The gross efficiency may be expressed in two ways after Rankine and D'Aubuisson - Addison (1964)

(a) if level B, tailwater level is taken as datum, then the useful work done per unit time is

$$\text{Energy supplied} = \frac{wqh}{wQh}$$

$$\text{Efficiency} = \frac{gh}{QH}$$

(b) if the head water level is taken as the datum then useful work done is

$$wq\ (h-H)$$

$$\text{Energy supplied} = wQH$$

$$\text{Efficiency} = \frac{q(h-H)}{QH.}$$

q, Q, h, H are as shown in Diagram VII and g is the accceleration due to gravity.

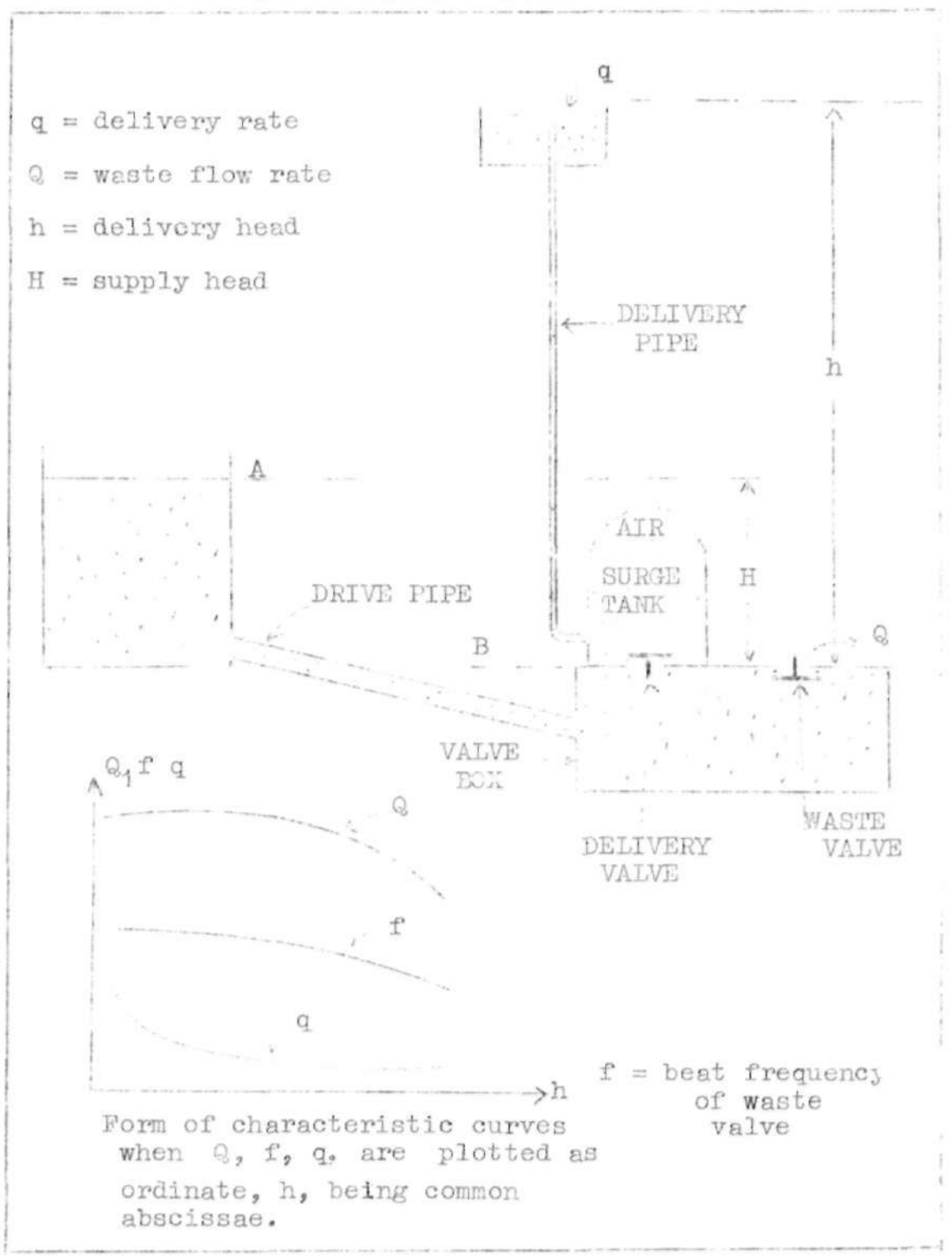
The efficiency is usually of the order of 75 percent. With this efficiency it is possible to raise almost 1/6th of the water supplied to the ram - (see efficiency graph Diagram VII)

Two factors render itunsuitable for use in this particular case

(a) the slope of the groundwater in the dry river bed is not steep enough to work the pump as it is 0.3 percent. If the slope is increased to 12.5 percent as required, then the pump has to be installed in a concrete man - hole below the groundwater table. There is therefore no economical way of getting away the waste

DIAGRAM VII

THE HYDRAULIC RAM PUMP



Form of characteristic curves when Q, f, q, are plotted as ordinate, h, being common abscissae.

water.

(b) the ram does not need much attention and works without fuel, the disadvantage being considerable wastage of water, which is of importance to the farmers as the quantity of water is one of the controlling factor in the irrigation scheme.

(iv) The centrifugal pump

This is the type of pump in most common use. It is generally of the horizontal spindle type with a volute casing in which the kinetic energy of the water as it leaves the impeller is converted into useful pressure. It is used for almost all quantities of discharges and pressures. It may also be of the mixed flow type in which the impeller blades are set at an angle to the axis of the pump so that a screw effect may be produced in addition to the centrifugal action - Allen (1960). This method enables the horse-power to be kept practically constant under different conditions of head and the engine can be run at or near full load under all conditions.

Generally these pumps are relatively low in initial

cost, are very dependable and durable, with low maintenance costs. They are capable of delivering large quantities of water and can pump sandy, gritty and muddy water without injury to the pump.

For the particular case of 40 gpm the brake-horse power required for the pump is approximately 0.4 H.P A typical pump with this characteristic is the type C1½v centrifugal petrol driven pump of Auto Diesel Limited (1969). It is portable lightweight, easily handled and adaptable for most irrigation purposes. The price of this pump is used in the calculation of the benefit to cost ratio of the project.

The pump's characteristics are as illustrated in Fig. V.

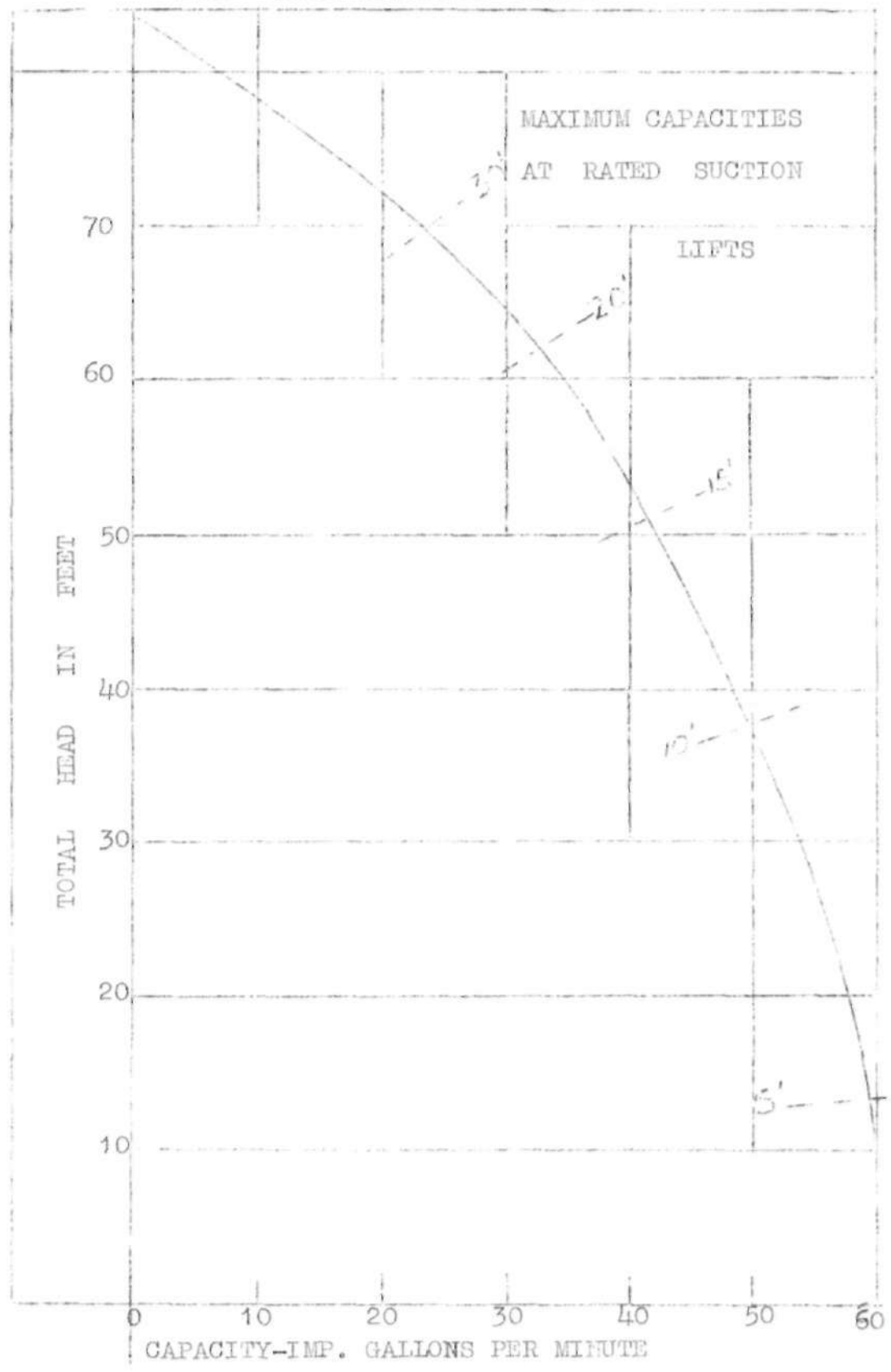

PUMP CHARACTERISTIC CURVE
MAXIMUM CAPACITIES
AT RATED SUCTION
LIFTS
25'
20'
15'
10'
5'
70
60
50
40
30
20
10
HEAD IN FEET
TOTAL
0
10
20
30
40
50
60
CAPACITY-IMP. GALLONS PER MINUTE

FIG. V

PART VII

IRRIGATION FARM PROJECT PLANNING

7.1 Introduction

The first consideration in the design of a farm project is to reconcile the twin limitations of available water supply and the area to be irrigated. For project planning, consideration must be given to the following items:-

(i) irrigation requirement

(ii) consumptive use of water

(iii) irrigation efficiency

(iv) commandable area

(v) cropping pattern

7.2 Irrigation requirement

For agricultural crops such as rice, tomatoes, onions, wheat etc. there is an optimum water requirement which varies from crop to crop and from time to time during the growing seasons depending on certain climatic factors such as temperature, humidity, and the amount of sunlight in a given locality. Israelsen et al (1967). In addition to the water actually trans-

pired by the plant in the process of growth (known as the consumptive use) water is lost unavoidably through

(a) evaporation from the bare soil between the crops,

(b) evaporation during conveyance of water to the plants,

(c) percolation beyond the root zones, and

(d) surface waste, the amount of which depends on the experience of the farmer.

The irrigation requirement is therefore the sum total of the water needed for plant growth i.e. consumptive use and the unavoidable losses.

7.3 Consumptive use of water

Researchers on consumptive use of water such as Blaney-Criddle and Penman have suggested methods of determining crop requirements from climatological data - Olivier (1961).

(i) Blaney- Criddle method

Working in the western United States of America as senior Irrigation Engineers, Blaney and Criddle established an empirical relation between weather and crop factors and water use. The formula has very little theoretical basis and is apprently rather illogical, but

it works. It is acceptable as a first approximation, for the determination of evapotranspiration, as it is based on climatic data mostly available throughout the year in most places in Nigeria. The formula, expressed in mathematical form, is as follows:

$$U = Tpk_1 \quad \ldots\ldots\ldots\ldots \quad 7(1)$$

where U = Monthly water use in inches

T = mean monthly air temperature (^{o}F)

P = monthly % of daytime hours in the year

k_1 = a crop constant - dimensionless

U is summed up for the months of the growing season to arrive at the total amount of water in inches to bring the crop to maturity.

Some of the crops that may be cultivated during the dry season on the banks of the river are, onions, tomatoes, wheat and cotton. They have a crop constant of 0.70. The consumptive water use for any of these crops is shown in Table XIII

TABLE XIII

Consumptive use -- Blaney-Criddle

Month	T	P	k_1	U
September	75.4	.082	.70	4.3
October	75.9	.083	.70	4.4
November	74.9	.078	.70	4.1
December	72.3	.799	.70	4.0
January	72.3	.080	.70	4.0
February	75.5	.074	.70	3.9
March	81.3	.084	.70	4.8
April	83.7	.084	.70	4.9
May	80.9	.088	.70	5.0
		Total =		39.4

Average U per day = 0.14 inch

peak = 0.16 inch per day in May

(ii) Penman (1948) developed a more firmly based theoretical approach to potential evapotranspiration. He states that evaporation depends upon:

(a) the supply of heat energy, since energy is required to evaporate water, and

(b) the drying power of air.

His analysis results in the expression:-

$$\frac{X_1 H + 0.27 E_a}{X_1 + 0.27} \quad \ldots\ldots 7.2$$

where E_T Consumptive water use in mm per day

X_1 = slope of saturated vapour pressure curve of air at absolute temperature in ^{o}F (mm Hg/^{o}F)

H = daily heat budget at surface in mm H_2O/day

E_a = Evaporation in mm of water/day.

In practice Penman's estimate requires more meteorological information than that of Blaney and Criddle.

From the meteorological data obtained from the 2nd Order Meteorological Station Samaru Zaria, the potential evapotranspiration during the dry season is as shown below:

TABLE XIV

Consumptive use - Penman

Month	Days	E_T (inches)
September	30	5.31
October	31	6.18
November	300	5.17
December	31	4.97
January	31	5.22
February	29	6.04
March	311	7.32
April	30	7.55
May	31	7.35
Total	274	47.71

Average = 0.174 inch per day

Peak = 0.25 inch per day in April.

(iii) Results from a weighing lysimeter studies (Samaru) also show that on the average the consumptive use is 0.15 of an inch per day during the rainy season. Owing to advection of energy in the form of warmer air coming from the Sahara desert (Oasis effect) the consumptive use of water can be as much as 0.40-0.50 of an inch per day during the months of February and March. - Kowal and Stockinger (1969)

(iv) From the actual water balance study of Samaru Dam Catchment Basin - Omolokun (1968), the evapotranspiration rate per day is 0.19 of an inch during the period when the bulk of vegetative growth of crops occurs.

(v) Some Agriculturists in the Agricultural Research Institute of the University have carried out research work on crop production including tomatoes, onions, wheat, sorghum and maize - Quinn et al (1969). From their data, it was observed that the yield of tomatoes was maximum when supplied with 2 inches of water per week which may be assumed as the irrigation requirement

which includes consumptive use and the unavoidable waste - all put approximately at 0.29 of an inch per day.

In conclusion the consumptive use of water by crop in this area may be taken with reasonable reliability as 0.20 of an inch per day.

7.4 Irrigation efficiency

The percentage of irrigation water that is available for consumptive use is termed irrigation efficiency and caters for all the unavoidable losses. It could be improved upon by experience or through the results of study of method for evaluating irrigation system on the area. Of the different system, sprinkler systems appears theoretically to give the highest efficiency -- Agricultural Handbook No.82 (1956).

For the site conditions on the banks of River Kubanni the irrigation efficiency may be put at 70%. The irrigation requirement works out approximately to be 0.3 inch per day or 6,800 gallons per acre per day.

7.5 Commandable area

Using the operational yield from the 20 x 20 x 2

feet 'pond' and the irrigation requirement of 6800 gallons per day per acre, the total area that can be commanded works out to be 2 acres per pond.

At the present a farmer hardly get enough water to manage ¼ acre throughout the dry season. With this development he can increase his farms capacity at least 8 folds. The benefit to cost ratio of the scheme as shown in Appendix III works out to be 4.19:1. This does not include other indirect benefits such as greater employment opportunity, improved health, and increased national income.

The total irrigable area as shown in Map II works out to be 1,040 acres. Only 251 acres could be irrigated using 'ponds' if these were spaced at approximately 600 feet apart.

7.6 Cropping pattern

Continuous cropping of the same crop pattern on the land is undesirable as this will encourage a build-up of nematodes in the soil which limits crop production or the yield may even be nil after some years - Quinn (1969). The following cropping pattern is

therefore suggested.

TABLE XV

Cropping pattern

Period	Crop	Source of water
OCT.-JAN	Onion	Underground
FEB.-APRIL	Tomato	Underground
MAY - OCT.	Sorghum	Rain

From year to year wheat may be introduced on one acre in rotation during the period of October to February. Cotton may also be introduced as a supplementary crop.

PART VIII

CONCLUSION

8.1 Summary

(i) It has been shown in the groundwater contour map that the aquifer is vast and the groundwater exists in gradient form and its direction of greatest declivity is towards the river course which locates the best yielding well sites in the basin.

(ii) It has been assessed that the yield from each small scale excavation lined with sorghum stalks in the river bed is just sufficient for a small scale irrigation project with an area of 2 acres.

(iii) It was ascertained that both the land and water can be classed as suitable for irrigation.

(iv) It is evident from the analysis of the water lifting devices that the centrifugal pump is the most suitable as it is easily adaptable for most irrigation needs viz. using it directly to feed sprinklers or furrows as it is capable of maintaining a constant discharge.

(v) A ratio of benefit to cost of 4:1 indicates that the project is economically desirable and should commence.

(vi) However, the activities of the Agricultural Department and the Health and Social Welfare Department will have to be co-ordinated in the irrigation project area, to enable scientific growth of planned cropping and the development of the cultural, economic and health aspect of the community.

It is not suggested that groundwater should supplant the water from surface storage for irrigation. Nevertheless, it does appear that the groundwater can be used not only to supplement but also to complement the rainfed crop schemes.

Experience over a number of years has shown that in most parts of Northern Nigeria that there are few potential dam sites since the river and stream valleys are wide and the area to depth ratio of the reservoirs is too large from an economic point of view. Evaporation and seepage losses may be as much as 6 feet per year most of this loss occurring during the

dry season since the evaporation rate is adequately maintained during the rainy season. As example of such a dam is the Samara Dam which has a surface pond area of 44 acres and from which almost 150 acre-feet of water is lost per year by evaporation. In fact, for the past 5 years it has not been possible to irrigate more than 5 acres per year using the dam-Kowal (1969).

The advantage of this small groundwater irrigation scheme is that a small capital investment can be used to implement it and will give the immediate relief to the pressing problems of the local farmers.

8.2 Financing the project

As all local farmers would benefit from the availability and development of groundwater, it is hoped that they would support plans to develop a sound groundwater supply. The feasibility of any groundwater development is contingent upon two major factors namely:

(i) physical feasibility and

(ii) economic feasibility

In short money must be made available by the local farmers either individually or as a group in the form of

a co-operative society, or through a state government subsidy to invest on the groundwater resources development. Investment loans on such a project would almost certainly yield a good return.

8.3 Suggestions

(i) The present study merely concerned itself with tapping the groundwater from a little below the water-table depth. In many areas in Northern Nigeria having no perenial streams there are wide river beds with considerable depths of sand which hold limited amounts of water replenished mostly by floods of various intensity during the rainy season and groundwater seepage in the dry season. The storage capacity of the sand bed can be improved upon by building a low resistance, modified homogeneous earthen dam or a hydraulic dam across the river thereby allowing the last of the floods to percolate into the river bed material. Only a small amount of the water will be lost to the atmosphere by evaporation as the cappillary rise in coarse sand does not exceed a few inches. Observations revealed that in the

Kubanni river bed it varies between 6 to 10 inches throughout the dry season. The improvement of the storage of water in such river beds could be of exceptional value and a great opportunity for water conservation practice.

(ii) To derive a better yield from wells the entire groundwater basin should be explored to determins the various factors in the groundwater equate which is merely that of the hydrologic equilibruim and may be simply put as:

$$a+b+c+d+e+f = a_1+b_1+c_1+d_1+e_1+f_1 \quad \ldots\ldots 8.1$$

where a is surface inflow

b is subsurface inflow

c is precipitation

d is imported water

e is decrease in surface storage

f is decrease in groundwater storage

a_1 is surface outflow

b_1 is subsurface outflow

c_1 is consumptive use

d_1 is exported water

e, is increase in surface storage

f, is increase in groundwater storage

The equation involves many factors which cannot be evaluated directly and that makes its solution impossible without making some assumptions which may be incorrect or inaccurate. The techniques applied for its solution thus mainly hinge on the scientific study of the basin characteristics (both hydrologic and geologic) and the periods for balance in order to reduce the number of unknowns in the equation to as few as possible. Usually it take many years of careful study to reach a reliable conclusion.

In the final analysis we may discover that the gain in groundwater storage which is the amount that can be abstracted without 'mining' the groundwater is approximately 4 percent of the average annual rainfall. In this catchment basin the amount is almost 2 inches of rainfall over the whole catchment surface drainage area. It is only practically possible to withdraw a part of this amount using tube wells or collector wells of some 15-20 feet diameter with infiltration galleries most of

which must be in the upstream direction of the river course.

The financial aspects of such ventures are definitely beyond the financial resources of the local farmers. It is therefore suggested that the state government should take up this work and the farmers can then pay back over a period of some years (say 40 years) on no profit and no loss basis. Until then the farmers would have no alternative than to depend on the shallow excavation in the dry river bed, the water yield of which is just sufficient for 251 acres out of the 1020 acres adjudged suitable for irrigation on the plateau strip of the catchment basin.

APPENDIX I

SUMMARY OF METEOROLOGICAL OBSERVATIONS AT SAMARU

LATITUDE 11°11'N LONGITUDE 7°38'E Alt 2250 ft Above sea level.

OBSERVATIONS	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	REMA
°Temperature °F 1938-68	72.3	75.7	81.4	83.7	80.9	77.5	75.1	74.3	75.6	76.8	7[illegible]	72.6	mean=76.7
Relative-10 a.m.	24.5	22.8	31.8	54.0	69.7	78.9	84.4	86.3	82.3	70.2	38.6	26.7	55.9
Humidity-4 p.m.	13.8	11.8	14.9	28.1	44.7	58.9	67.7	71.7	64.0	43.4	21.5	16.1	38.1
1954-68 sunshine daily mean hours	8.9	9.6	8.7	8.0	8.3	7.8	6.2	4.9	6.9	9.0	9.7	9.3	Average=8 Records : Cambell : Recorder
Soil Temp. at °F													Base per
1' - 0"	73.1	78.1	84.0	86.6	85.6	81.7	79.6	78.0	79.1	80.0	77.4	75.1	of recor
4' - 0"	78.1	78.8	82.3	85.0	84.5	81.8	81.5	80.4	80.7	81.3	80.3	79.1	1954-196
1954-1968 Evaporation "Pinche" in inches	13.17	14.01	15.56	9.04	6.74	3.66	2.65	2.24	2.53	5.18	9.85	11.79	Average= or 0.26 per day
Rainfall in inches	0.01	0.05	0.32	1.44	4.83	6.57	8.70	11.25	9.19	1.46	0.05	0.00	Base pe: of Reco: 1924-19
Days or Rain	0.1	0.2	1.0	4.0	10.0	13.3	16.2	20.6	16.8	3.9	0.2	0.00	Base pe of Reco 1924-19

APPENDIX II

STATISTICAL ANALYSIS OF K Values

STATION	K_i	$k_i-\bar{k}$	$(k_i-\bar{k})^2$
1	1.65	-0.15	0.0225
2	1.79	-0.01	0.0001
3	1.85	+0.05	0.0025
4	2.01	+0.12	0.0144
5	1.73	-0.07	0.0049
6	1.63	-0.17	0.0289
7	1.81	+0.01	0.0001
8	1.92	+0.12	0.0144
9	1.74	-0.06	0.0036
10	1.53	-0.27	0.0729
11	1.69	-0.11	0.0121
12	1.75	-0.05	0.0025
13	1.74	-0.06	0.0036
14	1.81	+0.01	0.0001
15	1.93	+0.13	0.0169
16	2.21	+0.41	0.1681
17	1.90	+0.10	0.0001
18	1.67	-0.13	0.0169
19	1.79	-0.01	0.0001
20	1.75	-0.05	0.0025
Σ_1^{20}	35.90		0.3872
$\Sigma_1^{20}/20$	1.795		0.01936

$$\bar{k} = \frac{1}{20} \sum_{i=1}^{20} k_i = \frac{1}{20} \times 35.90 = 1.80 \text{ ft/hr.}$$

$$s^2 = \frac{1}{20} \sum_{i=1}^{20} (k_i - \bar{k})^2 = \frac{1}{20} \times .3872 = 0.019 (\text{ft/hr})^2$$

$$s = 0.138$$

$$Cv = s/\bar{k} = \frac{0.138}{1.80} = 0.072 \text{ say } 7\%$$

k = 1.80 ft/hr

1.80 ft/hr. or 43.25 feet/day.

APPENDIX III

ECONOMIC FEASIBILITY OF THE SCHEME

The economic feasibility of the project has been worked out on the basis of the income from the crop production to the farmer at the farm site. In the analysis, two crops onion (September to January) and tomatoes (February to May) are considered. The total crop area to be irrigated per pond being 2 acres only.

Annual Expenditure (COST)

(i) Life of Pump = 5 years

(ii) Life of suction and delivery pipes = 10 years

(iii) Annual cost of the pump = £16 -. -.

(iv) Annual cost of the pipes = £2 -. -.

(v) Annual cost of the well = £2 -. -.

(vi) Annual maintenance cost of the pump at 33⅓% of annual cost (say) = £6. -. -.

(ii) Farm development including construction of channels etc. @ £40 per acre = £80. -. -.

(iii) Labour - fertilizers, pesticides and harvesting (onions) @ £50 per acre = £100. -. -.

(iv) Labour - fertilizers, pesticides and harvesting tomatoes @ £120 per acre = £240 -. -.

Total = £420

Add: contigences @ 10% = £ 42

Grand Total = £462

Total annual production cost = £29 + £462

= £491

Annual Income

(i) Yield of onions @ 20 tons per acre = 40 tons

(ii) Yield of tomatoes @ 25 tons per acre = 50 tons

(iii) Income from onions @ £30 per ton = £1200.-.-.

(iv) Income from tomatoes @ £18 per ton = £ 900.-.-.

Total = £2100.-.-.

Deduct income tax @ 2% = £ 42.-.-.

Net income = £2058.-.-.

Annual benefit to cost ratio = $\frac{2058}{491}$

= 4.19:1

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